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Table of Contents

Table of Contents (Cont.)

Table of Contents (Cont.)

A network of experimental forests and ranges: Providing soil solutions for a changing world

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Abstract
The network of experimental forests and ranges of the USDA Forest Service represents significant opportunities to provide soil solutions to critical issues of a changing world. This network of 81 experimental forests and ranges encompasses broad geographic, biological, climatic and physical scales, and includes long-term data sets, and long-term experimental manipulations. Examples of knowledge gained from individual experimental forests and ranges, and from cross-site studies of these valuable research sites are provided herein.

Key Words
Research networks, experimental forests, long-term research.

Introduction
The Experimental Forests and Ranges (EFRs) of the Forest Service, U.S. Department of Agriculture, were established to represent major forest vegetation types of the United States, to help provide science-based answers for management of the nation's forests and ranges, and to serve as "outdoor classrooms" to educate land managers and the public. The first Experimental Forest, Fort Valley Experimental Forest in Arizona, was established in 1908. Data collected from EFRs during the last 100 years can be used to address regional and continental scale questions about forest and range management, key forest ecosystem processes, wildlife habitat requirements, watershed management, and other topics, including soil processes. Research from the network of 81 Experimental Forests and Ranges can also address critical questions related to soil productivity, carbon storage, protection of water quality, remediation of pollution, and help provide soil-based solutions for our changing world.

Why this network?
The network of EFRs spans broad geographic and environmental ranges, from the tropical forests of St. Croix in the US Virgin Islands and Hawaii to boreal forests in Alaska (Figure 1) (Adams *et al.* 2008). The elevation of these research properties ranges from 30 meters (m) (Silas Little Experimental Forest in New Jersey) to 3500 m in the alpine Glacier Lakes Ecosystem Experiments Site (GLEES) in Wyoming. The EFRs occur in 26 provinces or ecoregions defined by Bailey (1995), representing more than 55% of the area of the continental U.S. The coterminous United States has 38 Holdridge life zones (Lugo *et al.* 1999), of which at least 14 contain experimental forests or ranges. The network also includes six subtropical life zones in the Caribbean, 5 tropical life zones in Hawaii and several boreal zones in Alaska. Sites in the EFR network represent 11 of the 12 soil Orders in the U.S. Soil Taxonomy System (Table 1, Soil Survey Staff 2006), and most parent materials from volcanics to alluvial materials to solid rock to organics and glacial materials. This broad geographic spread, covering nearly 50 degrees of latitude, results in the network reflecting a great range of temperature, precipitation, and vegetation conditions (Lugo *et al.* 2006). There are even experimental forests located within or near large urban areas (Baltimore Ecosystem Study, Maryland, and San Dimas Experimental Forest, California) addressing questions of urban ecosystem structure and function and the wildland/urban interface.

The network of EFRs also includes sites with extensive long-term data sets on climate, vegetation, and hydrology. Hydrological and meteorological data have been collected at most experimental watersheds for decades, in some cases for as long as 70 years, and are now easily accessed through a web-based data harvester system (*www.fsl.orst.edu/climhy/hydrodb/*). Long-term soil data are not as common, but examples do exist of important contributions to understanding long-term soil processes, such as the Calhoun Experimental Forest in South Carolina. There, long-term observational and experimental studies of soil processes have examined soil change at multiple time scales, from the decadal to millennial.

Table 1. Soil Orders represented within the USDA Forest Service Network of Experimental Forests and Ranges.

Alfisols
Andisols
Aridisols
Entisols
Gelisols
Histosols
Inceptisols
Mollisols
Oxisols
Spodosols
Ultisols

The work is particularly noteworthy for documenting soil recovery processes following abandonment after protracted agriculture for cotton (*Gossypium hirsutum*) and associated accelerated soil erosion, followed by planting to loblolly pine (*Pinus taeda*) (Richter and Markewitz 2001).

Many EFRs also are sites for long-term manipulative research, which help us to understand the effects of various disturbances on ecosystem processes and components over longer temporal scales. For example, a long-term study of the effects of silvicultural practices on Appalachian hardwood forest composition and growth on the Fernow Experimental Forest (West Virginia) was recently used by Davis *et al*. (2009) to compare carbon storage resulting from these different cutting practices over a 55-year-period. Many of the Experimental Forests have similar research studies evaluating silvicultural treatments over multiple decades which could be used to address these questions on regional to national scales. The long-term silvicultural and fire ecology study sites on the Escambia Experimental Forest (Alabama) have provided "living laboratories" available to university and agency researchers working to unravel the interconnecting processes essential to restoring the once-extensive longleaf pine (*Pinus palustris*) forest ecosystem.

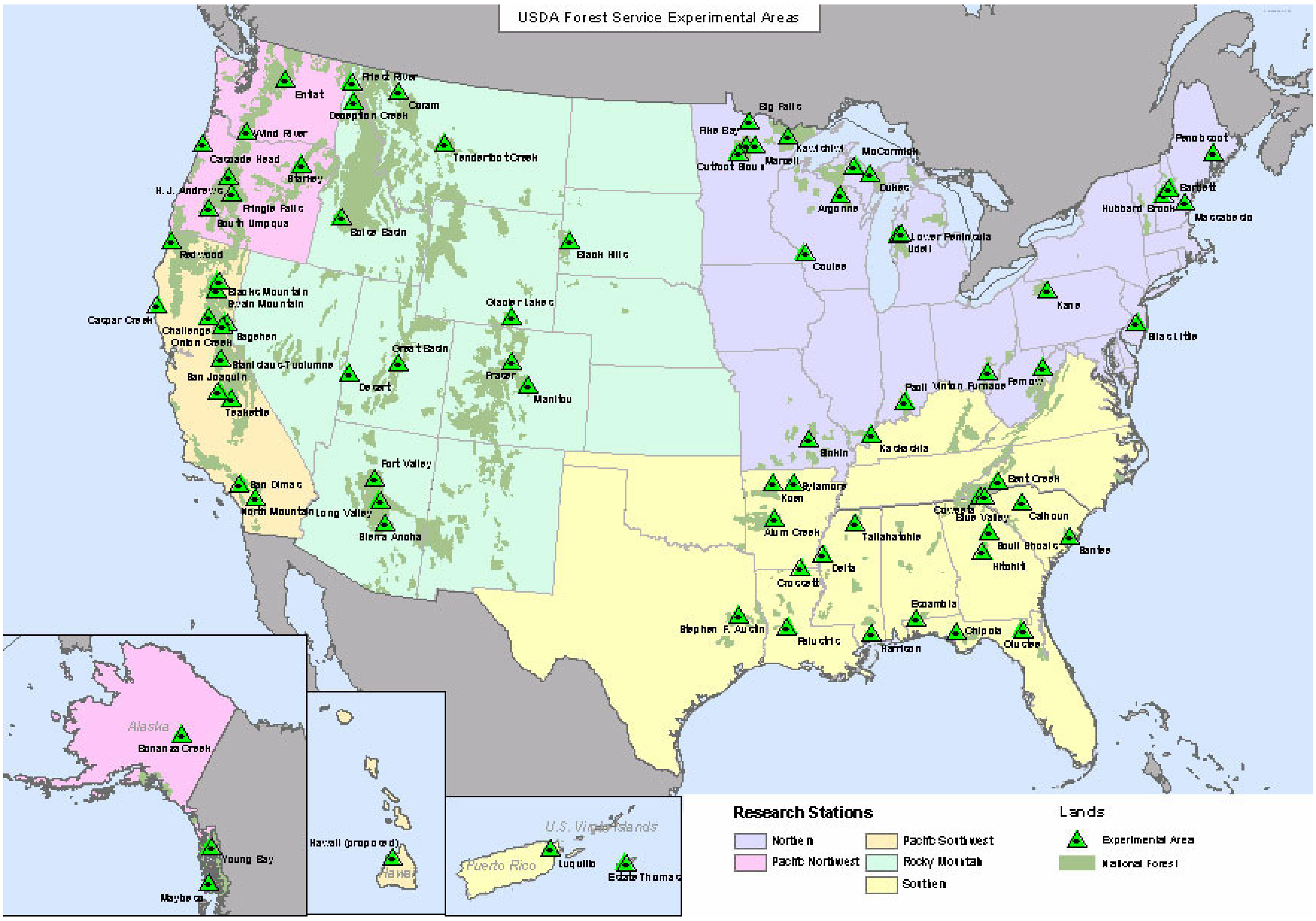
Because EFRs are dedicated to long-term research, they provide an excellent opportunity to understand ecosystem processes over many decades. For example, research at Hubbard Brook Experimental Forest (New Hampshire) was instrumental in documenting acidic deposition and its effects on soil and water chemistry in north America. Data from more than 50 years of research on the Marcell Experimental Forest in Minnesota has been used to understand peatland functions in northern ecosystems, develop peatland hydrologic models, and develop research and monitoring programs that have later expanded nationally and internationally.

Opportunities Associated with EFRs

Finally, there are opportunities associated with the network of EFRs. These arise from the ability to link studies from different ecoregions, soil or vegetation types to study landscape scale processes and questions. For example, as part of studies of carbon dynamics under the USDA Global Climate Change Program, scientists are linking intensive ground-based measurements of carbon stocks, forest growth, and climate from experimental forests with spatially extensive but coarse resolution measurements. Through this work, scientists at the Bartlett Experimental Forest in New Hampshire, the Marcell Experimental Forest in Minnesota, the Fraser Experimental Forest in Colorado, and GLEES are linking landscape monitoring to carbon management at a scale relevant to local land management decisions.

The opportunity also exists for studying impacts of human activities by using manipulative experiments at a variety of sites, or to conduct experiments with similar treatments at several EFRs. Because EFRs are set aside for manipulative research, these experiments are protected for the long term – much longer than is generally possible in an academic setting. Opportunities exist to address important issues relative to challenges of managing forests and ranges in a changing world, using long-term data available from EFRs. For example, at Priest River Experimental Forest in Idaho, daily weather records dating back to 1911 have been used in large-scale models to predict continental scale vegetation changes resulting from climate change.

Finally, the Forest Service network of EFRs is linked with other research and monitoring networks, further increasing the information available, and the opportunities for synergistic research efforts. These networks include the National Atmospheric Deposition program, the Long-Term Ecological Research (LTER) network and National Ecological Observatory Network (NEON) of the National Science Foundation, and the Long-Term Soil Productivity study, to name only a few. The Forest Service EFRs also are part of a larger USDA association of long-term research sites, particularly suited to addressing issues of a changing world (Moran *et al*. 2008).



References

Adams MB, Loughry L, Plaugher L Eds. (2008) Experimental Forests and Ranges of the USDA Forest Service. General Technical Report NE-321 (Revised) [CD-ROM] (USDA Forest Service, Northern Research Station Newtown Square, PA).

Bailey RG (1995) Description of the ecoregions of the United States. 2nd ed. rev. and expanded Misc. Pub. No. 1391 (rev.) (USDA Forest Service, Washington, DC).

Davis SC, Hessl AE, Scott CJ, Adams MB, Thomas RB (2009) Forest carbon sequestration changes in response to timber harvest. *Forest Ecology and Management* **258**(9), 2101-2109.

Lugo AE, Swanson FJ, Gonzalez OR, *et al.* (2006) Long-term research at the USDA Forest Service's Experimental Forests and Ranges. *Bioscience* **56**(1), 39-48.

Lugo AE, Brown SL, Dodson R, Smith TS, Shugart HH (1999) The Holdridge life zones of the conterminous United States in relation to ecosystem mapping. *Journal of Biogeography* 26, 1025-1038.

Moran MS, Peters DPC, McClaran MP, Nichols MH, Adams MB (2008) Long-term data collection at USDA experimental sites for studies of ecohydrology. *Ecohydrology* **1**(4), 377-393.

Richter DD Jr, Markewitz D (2001) Understanding Soil Change. (Cambridge University Press. Cambridge, UK).

Soil Survey Staff (2006) Keys to Soil Taxonomy, 10th ed. (USDA-Natural Resources Conservation Service, Washington, DC).

A simple method for the determination of nitrate in potassium chloride extracts from forest soils

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Abstract
We developed a simple method to determine NO_3^--N in KCl extracts from forest soils. The measurement principle of the method is based on the difference of the spectral adsorption properties between dissolved organic carbon (DOC) and nitrate. In this method, NO_3^--N concentration was obtained by measuring the absorbance of KCl extracts at 220nm and 260nm wavelengths. We term this method as the UV method. We measured NO_3^--N concentration of fifty six KCl extracts from six forest soils in central and western Japan by using the UV method. The results were highly correlated to those by the automated Cd reduction method. It suggests that the UV method is a reliable method to determine NO_3^--N in KCl extracts. It is the most simple procedure to determine NO_3^--N in KCl extracts from forest soils.

Key Words
Nitrate, rapid determination, forest soils, available nitrogen, nitrogen mineralization.

Introduction
Nitrogen is a most important nutrient for higher plants, so available nitrogen and nitrogen mineralization potential of soils are indicators for soil fertility. This nitrogen is evaluated by the amounts of NH_4^+-N and NO_3^--N that are extracted with KCl solution from soils. For determining NO_3^--N, expensive equipments or time consuming methods such as flow injection (automated Cd reduction methods) and Kjeldahl determination method are needed. So, several rapid methods have been devised for NO_3^--N determination (Cataldo *et al.* 1975; Kanno *et al.*1968; Norman and Stucki 1981; Sakata 2000; Yang *et al.* 1998). Yang *et al.* (1998) developed a simple method by applying the salicylate method (Cataldo *et al.* 1975;Kanno *et al.*1968). This method is very simple but it needs some steps such as reagent adding and heating.

The aim of this study was to develop more simple method for determining NO_3^--N in KCl extracts. NO_3^--N could be determined by a UV absorption method in solution where the dissolved organic carbon (DOC) concentration is low. The UV absorption method, however, cannot be applied for the determination of NO_3^--N in KCl extracts from forest soils because these solutions usually contain considerable amount of DOC. DOC absorbs light at all wavelengths between 200 nm and 300nm. The absorbance of DOC gradually decreases from 200 nm to 300nm. On the other hand, NO_3^--N also absorbs UV light at less than 250 nm wavelength. Based on the difference of UV absorption properties between DOC and NO_3-$^-$N, we developed a NO_3^--N determination method.

Methods
Fourteen surface soil samples were collected from the forests in Mt. Tsukuba and Mt. Kaba, Ibaraki prefecture, Japan (Table 1). DOC was extracted from each soil by 100 ml of water added to 20g of Soil. NO_3^--N in the extracts was removed with ion exchange resins (the mixture of Amberlite IR120 and Amberlite IRA410). We measured absorption spectra of each extract within 200 nm to 300 nm by a spectrophotometer (Shimadzu UVmini-1240). We calculated the ratio of the absorbance at 220nm to that at 260nm in each extract and used the mean value of the ratio in the following nitrate estimations. NO_3^--N was extracted with 2M KCl solution from thirty-nine soil samples collected from a Japanese cedar forest and a Japanese cypress forest in Mt. Tsukuba. We measured the absorbance at 220nm and 260nm in each 2M KCl extracts. We also measured the absorbance at 220nm and 260nm of 2M KCl extracts from seventeen soil samples that were collected in forests in Kobe, Ehime and Kagoshima in western Japan. Then, the 220nm absorbance originated from NO_3^--N ($[UV220]_{NO3}$) was estimated by the following formula.

$$[UV220]_{NO3} = [UV220] - [UV260]* K_{220/260} \qquad (1)$$

Here, [UV220] is an absorbance value at 220nm in the extracts. [UV260] is an absorbance value at 260nm in the extracts. $K_{220/260}$ is the ratio of the absorbance at 220nm to that at 260nm originated from DOC.

Table 1. General information of soil samples and number of samples for water and KCl extraction.

Location	Latitude	Longitude	Vegetation[A]	Soil Type[B]	Parent Materials	Water extract Number	KCl extract Number
Tsukuba	36°10′N	140°10′E	Japanese cypress	BD	Volcanic Ash, Gneiss	2	20
Tsukuba	36°10′N	140°10′E	Japanese cedar	BD	Volcanic Ash, Gneiss	4	19
Kaba	36°18′N	140° 9′E	Deciduous Forests	BD(d)	Volcanic Ash, Granite	8	--
Kochi	33°28′N	133°00′E	Japanese cypress	BlD	Volcanic Ash	--	7
Kobe	34°43′N	135°10′E	Japanese cedar	BD	Tertiary sediment	--	6
Ehime	33°53′N	132°52′E	Mousoutiku Bamboo forests	BD(d)	Hornfels	--	4

[A]Japanese cypress: *Chamaecyparis obtusa*, Japanese cedar: *Cryptomeria Japonica*, Mousoutiku: *Phyllostachys pubescens.* [B]According to classification of forest soils in Japan (1975), BD: Moderately moist brown forest soils, BD(d) Moderately moist brown forest soils (drier subtype), BlD: Moderately moist black soils

NO_3^--N concentration at the KCl extracts was determined by comparing $[UV220]_{NO3}$ with the absorbancy of NO_3^--N standard solution. NO_3^--N concentration of each extract was also measured by the automated Cd reduction methods (Dia Instrument FI-N50). We call the former the UV method and the latter the automated Cd reduction method.

Results

The absorption spectra of DOC and NO_3^--N

Each water extract after deionization showed UV absorption, and its optical density was least at 300nm and gradually increased toward shorter wavelength (Figure 1). These extracts did not contain NO_3^--N, so the absorption curve observed was considered to be derived from DOC. On the contrary, the adsorption curve of NO_3^--N has no absorption in the range from 250nm to 300nm and abruptly increased at 240nm. The mean value of the ratio of absorbancy at 220nm to at 260nm was 1.543 in water extracts after deionization for fourteen soil/water extracts (Table 2), so we adopted 1.543 as the value of $K_{220/260}$ in the equation (1).

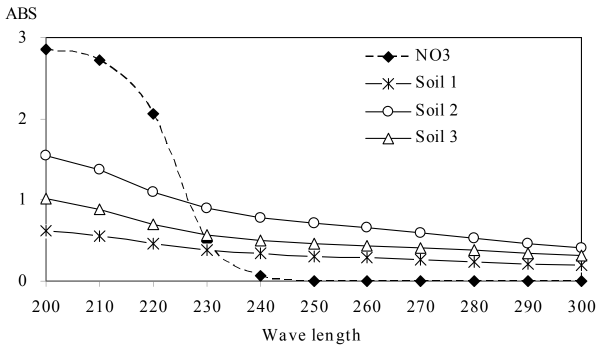

Figure 1. The absorption curves of three soil/water extracts after deionization and that of NO_3^--N solution.

The comparison of the UV method with the automated Cd reduction method

We compared the data by the UV method with those determined by the automated Cd reduction method for 2M KCl extracts from Mt. Tsukuba soils (Figure 2, left). There was a good relationship between the UV method and the automated Cd reduction method ($Y=1.040X-0.124$, R^2=0.993). If the absorbancy at 220nm of DOC was assumed to be 0, the slope of the regression line was 0.753. This indicated that NO_3^--N concentration by the UV method was overestimated compared with the automated Cd reduction method (Figure 2, right). We also compared both methods for NO_3^--N determination in KCl extracts from Kobe, Ehime and Kochi soils (Figure 3, left). The data for the UV method also were highly correlated with those by the automated Cd reduction method ($Y=1.099X-0.421$, $R^2=0.989$). On the other hand, in case no compensation was carried out for the absorbancy at 220nm, NO_3^--N concentration by the UV method was overestimated (Figure 3, right).

Discussion

Several simple methods have been proposed for the NO_3^--N determination (Cataldo *et al.* 1975; Kanno *et al.*1968; Norman and Stucki 1981; Sakata 2000; Yang *et al.* 1998). These methods are simple but they need some steps such as reagent adding and heating. The UV method, we developed, is more simple. It only needs only a spectrophotometer and the measurement of absorbancy at 220nm and 260nm. It is the most simple procedure to determine NO_3^--N in KCl extracts from soils.

Table 2. The ratio of absorbance at 220nm to at 260nm in soil/water extracts after deionization.

Location	Vegetation	Soil depth (cm)	UV220	UV260	K220/260
Tsukuba	Japanese Cypress	0-5	1.054	0.637	1.655
Tsukuba	Japanese Cypress	0-5	0.526	0.33	1.594
Tsukuba	Japanese Cedar	0-5	0.681	0.446	1.527
Tsukuba	Japanese Cedar	0-5	0.645	0.443	1.456
Tsukuba	Japanese Cedar	0-5	0.569	0.375	1.517
Tsukuba	Japanese Cedar	20-25	0.309	0.179	1.726
Tsukuba	deciduous Forests	0-5	2.382	1.551	1.536
Kaba	deciduous Forests	5-15	2.901	1.953	1.485
Kaba	deciduous Forests	15-30	0.457	0.287	1.592
Kaba	deciduous Forests	0-5	2.868	1.938	1.48
Kaba	deciduous Forests	5-15	0.31	0.204	1.52
Kaba	deciduous Forests	15-30	0.409	0.261	1.567
Kaba	deciduous Forests	0-10	1.059	0.717	1.477
Kaba	deciduous Forests	20-30	0.912	0.62	1.471
mean					1.543
Max.					1.726
Min.					1.456
S.D.					0.077

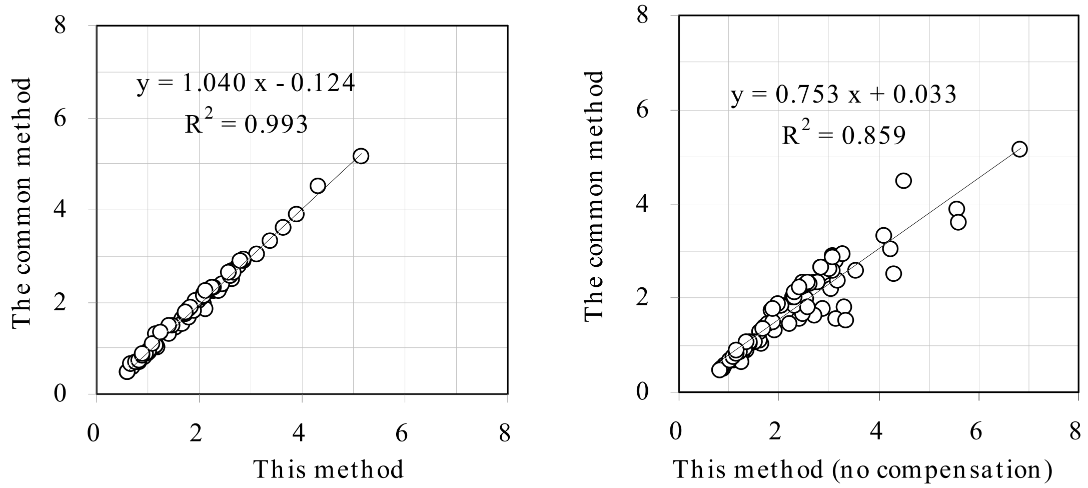

Figure 2. Comparison of NO_3^--N concentrations by the UV method (this method) with those by the automated Cd reduction method (the common method) for KCl extracts from Tsukuba soils (Unit is mg N/L). $K_{220/260}$ = 1.543 in the left figure. $K_{220/260}$=0 in the right figure.

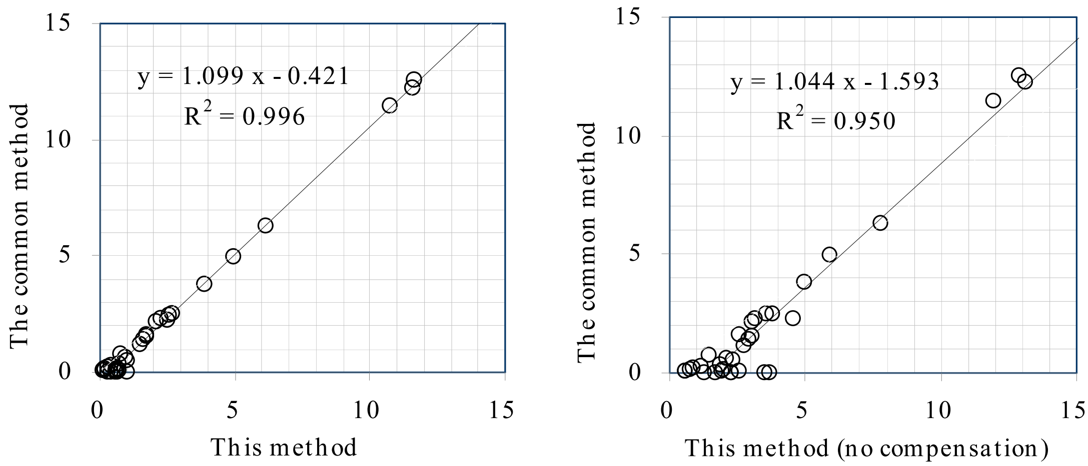

Figure 3. Comparison of NO_3^--N concentrations by the UV method (this method) with those by the automated Cd reduction method (the common method) for KCl extracts from Kobe, Ehime and Kagoshima soils (Unit is mg N/L). $K_{220/260}$ = 1.543 in the left figure. $K_{220/260}$=0 in the right figure.

The accuracy of the UV method depends on the value of $K_{220/260}$ in the equation(1). $K_{220/260}$ varied from 1.456 to 1.726 in the fourteen soil/water extracts. In the case of $K_{220/260}$ =1.456, the slope, the y-intercept and the R^2 of the regression line, are calculated to be as 1.064, 0.106 and 0.996 for the KCl extracts from Tsukuba soils, respectively. In the case of $K_{220/260}$ =1.726, the slope, the y-intercept and the R^2 are 1.027, 0.128 and 0.991, respectively. Each parameter is almost same in the case of $K_{220/260}$ =1.543 (Figure 2, left). This result suggests that the value of NO_3^--N estimation would be almost constant even if the value of $K_{220/260}$ varied to some extent. The NO_3^--N estimated by the UV method is highly correlated with values for the automated Cd reduction method for KCl extracts from forest soils in western Japan (Figure 3, left). However, as for the slope and the y-intercept of the regression line, the correspondence of two methods is somewhat low compared with the case of Tsukuba soils. The soil type of the Kochi soils is different from that of Tsukuba soils and vegetation for Ehime soils is different from that of Tsukuba soils (Table 1). We assumed that the $K_{220/260}$ of DOC is constant in KCl extracts from soils but the low correspondence suggests that the $K_{220/260}$ of DOC may vary with soil type and vegetation type. We need more information about $K_{220/260}$ of DOC extracted from soils under different environments.

Conclusion

The method that we developed to determine NO_3^--N in KCl extracts, only needs a spectrophotometer and the measurement of absorbance at 220nm and 260nm. We conclude that it is the simplest procedure to determine NO_3^--N in KCl extracts from forest soils.

References

Cataldo DA, Haroon LE, Schrader LE, Youngs VL (1975) Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. *Communications in Soil Science and Plant Analysis* **6,** 71–80.

Kanno S, Fukui S, Kaneko M (1968) Hygienic chemical studies on public water. VI. Determination of nitrate nitrogen in water sodium salicylic acid method. *Eisei Kagaku* **14,** 14-29 (In Japanese).

Norman RJ, Stucki JW(1981) The determination of nitrate and nitrite in soil extracts by ultraviolet spectrophotometry. *Soil Sci. Soc. Am. J.* **45,** 347-353.

Yang JE, Skogley EO, Schaff BE, Kim JJ (1998) A simple spectrophotometric determination of nitrate in water. *Soil Science Society of American Journal* **62,** 1108-1115.

An equation for yield prediction for *Pinus taeda* L. as a function of soil properties

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Abstract
This study was developed in order to obtain an equation for yield prediction as a function of soil properties, for plantations established with *Pinus taeda* L. in the plateau located in the northern part of the State of Santa Catarina, Brazil. As a case study, one of the farms of Battistella Florestal Ltd. was chosen. Data were obtained from permanent sample plots from a Continuous Forest Inventory as well as from a detailed soil map of a 2,252 ha forest estate. Soil properties and yield of *P. taeda* were analysed with stepwise multiple linear regression. By these means an equation was developed for site index prediction with 93.97 % precision. It was also found that soils with well developed surface drainage and high levels of organic matter are more suitably for growth of *P. taeda* under local environmental conditions.

Key Words
Multivariate statistical methods, soil survey, forest planning.

Introduction
Forest owners need low cost and precise information about stand yield before harvesting operations are implemented in order to improve planning of the supply to log yards as well as for planning purposes and forest inventory. Growth and yield of planted forests depend on physiological responses to the interactions between biotic and abiotic environmental factors. Climate, physiographic and soils factors are the most important environmental elements influencing productive capacity in a given location, these represent site quality (Carmo and Resende 1990). Soil class incorporates important information such as depth, texture, nutrient and organic matter, chemical activity of the coloyd fraction and compacted layers that could restrict root growth and water movement (Rigatto *et al.* 2005). On the other hand, there are few studies about the joint analysis of such factors and their correlation with different ecosystems, site quality and pine species. Evaluation of potential and limiting factors affecting environmental quality for productive capacity of forest site evaluation cannot be based on isolated attributes, but on a syntesis of qualities and limitations of the ecosystem from an integrated perspective. Hence, it can be observed that when physical, chemical and physical-hydric soil characteristics, geology, terrain and climate are jointly examined and correlated to the different scenarios, the overall ranking of the influences is easier (Van Den Berg 1995; Rigatto *et al.* 2005). On the other hand, understanding the behavior of ecosystems is difficult due to the complex interactions and quite frequently demands predictive models. For this reason, when a detailed analysis is needed in order to understand the relations between quantitative attributes of the trees and physical environment the choice of a statistical method that optimizes resources without reducing precision of the estimation process is of fundamental importance (Mello *et al.* 2005). In this context, and according to Bognola (2007), this research was conceived in order to study physical environmental factors affecting growth of *Pinus taeda* L. in a commercial plantation as well as to develop an equation for yield prediction using multivariate techniques and regression analysis.

Material and methods
Working area
The study was developed in one of the forest farms belonging to Battistella Florestal, and located on the plateau of the northern part of the state of Santa Catarina, Brazil, in Rio Negrinho e Doutor Pedrinho counties (Figure 1). Climate type is *Cfa* according to Köppen's classification (tropical climate, with warm Summer, without any dry season, average temperatures of the coldest month under 18°C and above -3°C). The rainfall of the region is high (1,700 mm/y) and well distributed over the year.

Data collection
Data were collected in 500 m^2 permanent sample plots of a Continuous Forest Inventory. In addition to DBH and height of individual trees, the following information was also obtained: a) physical, chemical and physical-hydric soil characteristics at 0–20 cm and 30–50 cm depth for all sample plots considered; b) aspect, geology and physiographic descriptive information obtained from a detailed soil survey (scale 1:10,000) of the area. Statistical analysis was performed using SAS® - Statistical Analysis System (SAS Institute Inc. 1993), licensed for Embrapa Florestas.

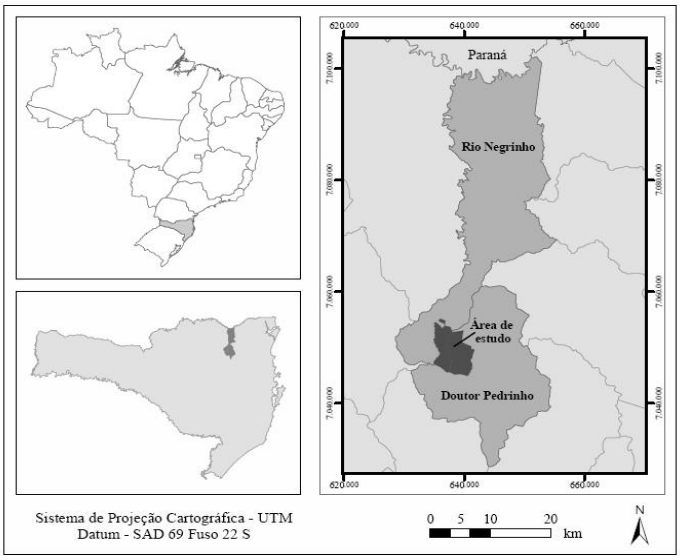

Figure 1. Working area location.

Regression Equation
A multiple regression analysis was performed using the following general linear model:
$Y_i = \beta_0 + \beta_1 X1_i + \beta_2 X2_i + ... + \beta_p Xp_i + \varepsilon_i$
where: Y_i is the observed value for the response variable (dependent) at the level i of the predictive (independent) variables X_i´s;
β_0 : regression constant (intercept of the regression equation with axis y);
β_1 : regression coefficient (variation of Y as a function of the variation of one unit of X1);
β_2 : regression coefficient (variation of Y as a function of the variation of one unit of X2);
β_p : regression coefficient (variation of Y as a function of the variation of one unit of Xp);
$X1_i$: value of variable X1, at the level i;
$X2_i$: value of variable X2, at the level i;
Xp_i : value of variable Xp, at the level i;
ε_i : error or deviation associated with the distance of the observed value Yi and the corresponding estimated value $\hat{Y}_i$ based on the regression equation.

As the coefficient of determination always increases with the inclusion of new a independent variable in the equation, even if it has no relation with the dependent variable, the corrected coefficient of determination was used for the degrees of freedom as defined by Ribeiro Júnior (2001):

$$R^2_{adjusted} = \overline{R}^2 = R^2 - \frac{p}{n-p-1}(1-R^2)$$

where *p* sets the number of regression coefficients (not including β_0).
In practice there can be a large number of variables influencing the response. Hence, a stepwise regression procedure was adopted for the selection of the best regression model. This procedure determines that the first variable entering the model is the variable X with the highest correlation with the response variable Y. Subsequently, through the largest values for the partial coefficient of determination of all other variables were not included in the model. The model is adjusted with the inclusion of the last variable and the values for the partial F test are determined. By those means any variable that produces a non-significant contribution (partial F) is removed from the model. This process continues until there are no other variables being added or removed (Lavoranti 2005).

Results

In order to identify the best regression equation for *P. taeda* plantations, for Site Index 15 (SI_15), based on 49 independent variables, related to physical environment characteristics, a principal component (PCA) multiple linear regression analysis was used. Regressive variables were selected in two stages: a) first, the most significant variables were identified by principal component and factor analysis; and b) the eleven most significant factors were identified and considered in a stepwise regression analysis. The reduction of variables through PCA has produced a 9 % loss of information on the total variance. In other words, the model developed with this procedure explained 91 % of the data variability. According to Royston (1992), an exploratory analysis has to be performed with the data in order to verify the normal distribution of the residuals for the structure of the regression model. In this context, it can be verified in Table 1 for the analysis of variance and, in Table 2, where the values for the coefficients of the regression model are defined. The variables selected are presented in equation 1.

Table 1. Analysis of variance for the multiple regression in the step 19 (stepwise method), for the set of independent variables of this study.

Source	D.F.	SQ	MQ	F_0	Pr > F_0
Regression	5	4.609,03071	921,80614	162,71	< 0,0001
Error	11	62,31929	5,66539		
Total	16	4.671,35			

$$SI\_15_{est} = b_1 KPA1\_10 + b_2 KPA2\_10 + b_3 HAL1 + b_4 DENSID1 + b_5 MO1 + \varepsilon \qquad \text{(eq. 1)}$$

Where:

SI_15est: Site Index estimated for *P. taeda* at age 15 years (m);
KPA1_10: Water removed from the soil (cm^3/cm^3), tension 10 kPa, for the surface layer (5 – 10 cm) (moisture content, at the field capacity – CC);
KPA2_10: Water removed from the soil (cm^3/cm^3), tension 10 kPa, for the sub-superficial layer (30 – 50 cm) (moisture content, at the field capacity – CC);
HAL1: exchangeable hydrogen + aluminum contents (cmolc dm^{-3}), in the superficial layer (5 – 10 cm);
DENSID1: Soil density (kg/dm^3) for the supeficial layer (5 – 10 cm);
MO1: Organic matter (g/dm^3), in the superficial layer (5 – 10 cm);
ε: Residual;
b_1,..., b_5: Coefficients of the model.

Table 2. Coefficients of the regression model.*

Coefficient (β_i)	Estimated Parameter	Error (ε)	t	p > t
b_1	-520.392	210.213	-247.555	0.03082
b_2	215.549	53.809	400.418	0.00207
b_3	0.01799	0.00768	234.109	0.03910
b_4	904.679	0.70485	1.283.509	< 0.0001
b_5	0.39932	0.06772	589.679	0.00010

* Coefficient of Determination: R^2 = 0.9867.

It was observed that among all variables selected for the development of the predictive model, those related to the physical-hydric soil properties were the most important in that they presented the highest values for the coefficient of correlation. The analysis of residual distribution as a function of the estimated values allowed the observation of homoscedasticy, as well as the absence of outliers. Fitting the model was adequate for all the extentions examined which justifies the used of the model for the estimation of Site Index as a function of the variables chosen.

Conclusion

The equation defined through multivariate regression analysis of the case study data allows site index estimates with a 93.97 % precision.

It was also found that soils with well developed surface drainage and high levels of organic matter are most suited for the growth of *P. taeda* under local environmental conditions.

References

Bognola IA (2007). Unidades de manejo para P. taeda L. no planalto norte catarinense, com base em características do meio físico. Curitiba, 160 f. thesis (DSc. Silviculture), Centro de Ciências Florestais, Universidade Federal do Paraná.

Carmo DN, Resende M, Silva TCA (1990) Avaliação da aptidão das terras para eucalipto. (NF Barros, NF, RF Novais) pp.187-235. (Relação Solo-Eucalipto: Viçosa, Folha de Viçosa).

Lavoranti OJ (2005). Análise de Regressão Linear Múltipla. Curitiba, 41f. Apostila da Discplina CE-216 do Curso de Pós-graduação - Setor de Ciências Exatas – Departamento de Estatística, Universidade Federal do Paraná (UFPR).

Mello JM, Batista JLF, Ribeiro Jr PJ, Oliveira MS (2005) Ajuste e seleção de modelos espaciais de semivariograma visando à estimativa volumétrica de Eucalyptus grandis. *Scientia Forestalis, Piracicaba, SP,* **69**, 25-37.

Ribeiro Júnior JI (2001) 'Análises estatísticas no SAEG'. (Viçosa: UFV).

Rigatto PA, Dedecek RA, Mattos JLM de (2005) Influência dos atributos do solo sobre a produtividade de P. taeda. *Revista Árvore, Viçosa* **29**, 701-709.

SAS - Statistical Analysis System (1993) 'Programa de computador, ambiente VM. Cary,versão 6.08'.

Van den Berg E (1995) Estudo florístico e fitossociológico de uma floresta ripária em Itutinga, MG, e análise das correlações entre variáveis ambientais e a distribuição das espécies de porte arbóreo-arbustivo. Lavras, MSc Dissertation, Federal University of Lavras.

Change of forest soils under human factors (the Komi Republic, Russia)

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Abstract
Timber, oil and gas industries play a dominant role in disturbances of forest soils. The greatest changes of soils happen in first 5-10 years after cutting. The cutting areas are characterized by different disturbances and various rates of renewal. Temporary soil over-moisturing in first years after cutting and secondary succession of vegetation influence soil morphology, soil properties and humic substances at cutting areas. Changes of soil and soil cover of the Komi Republic under impact of oil and gas industry are presented.

Key Words
Forest soils, anthropogenic changes of soils, cutting, oil and gas mining impact on soils

Introduction

The Komi Republic (KR) is located in the North-East of European Russia, its area is more than 40 million hectares. Bioclimatic conditions are not favorable for agriculture, but soil resources are of great importance for forestry (Zaboeva 1975). The European northeast is characterized by about 50 % forest-cover (State 2009). The total area of forest resources land is 36 million ha (or 86 % area of the KR). Soils of the podzolic type are dominant in well drained forest landscapes: gley-podzolic soils in northern taiga subzone, typical podzolic soils in middle taiga and sod-podzolic soils in the southern subzone. Soils of this groups are of great importance for forestry. Quite productive spruce and pine forests grow on such sod-podzolic soils. More than a half of the area covered by podzolic-boggy soils predominated on watershed sites under green-mosses and sphagnum dark coniferous forests (Zaboeva 1975).
Soil transformation (changes in morphological and physicochemical parameters) in the KR is connected with timber-harvesting and oil-gas industry. Agricultural lands (tillage, greenland and pasture) are insignificant and cover 418 thousand hectares – 1.0 % of KR total area (State 2009). In forest landscapes the specificity of soil and soil cover formation under native forest vegetation has been studied by now (Zaboeva 1975; Rusanova 1987; Lodygin *et al*. 2007; Soil..2001) and also under agriculture (Zaboeva *et al.* 1988; Kanev and Mokiev 2004). Problems linked with soil changes result from forest harvesting and oil - gas mining and pipeline have been less studied. The main objectives of the present research were to study some properties of podzolic soils in chronosequences of clear-cuttings, to evaluate the impacts of cutting on soil organic matter and the impact of oil and gas industry on properties of forest soils.

Materials and methods

Human-induced changes in soils have been studied in the northern and middle taiga subzones of the republic. Influences of harvesting operation have been estimated in middle taiga in two chronosequences: soils of the first series formed in loamy sediments (Ust'Kulom district, Komi), the second - in lithologically discontinuous deposits (sand underlayed by morain loams at depths of 40-50 cm) (Prilyzskii district, Komi). Soils of first chronosequence in clear-cutting sites (only "felling" sites without any mechanical disturbances of ground cover and soils as well) presented by: plot 1 – soils under native spruce forest; plot 2 – soils under 6-year-old clear cutting; plot 3 – soils under 38-year-old clear cutting. Soils of second chronosequence of clear-cuts presented by: plot 1 – soils under native pine forest; plot 2 – soils under 12-year-old clear cutting; plot 3 – soils under 23-year-old clear cutting. Additionally mechanically disturbed soils were investigated (tractor road and timber loading platform). Soils were described according to the Russian system of Soil Classification (Classification 2004). Analytic methods were used in accordance with the "Theory and practice of soil chemical analysis" (2005).

Results

Influence of timber cutting

Significant areas of forests (more than 20% of total KR area) were cut during the second half of the 20th century (1930 -1990s). Nowadays about 5 - 8 million m^3 wood is harvested annually (State 2009), mostly by clear cut. Reforestation of cutting areas is by secondary birch and aspen stands. According to Lal (2005) forest ecosystems contain a huge carbon content stored in soils as accumulated organic carbon. It is very important to understand the mechanisms of change in soil organic matter during secondary succession after forest cutting.

In the cutting area soil changes and restoration rate of physicochemical properties depend on the texture of soil-forming sediments, season of cutting, quality and technological characteristics of harvesting operations. Greatest changes of soil cover are affected by heavy forestry machinery during harvesting operation (Rosnovsky, 2001). This type of disturbances is very common for tractor road and timber loading platforms covering about 30 % of the cutting area. In these sites the upper soil profile consists of piling layers which appear to be a mixture of mineral soil and logging slash (stems, branches, etc.) and the ground cover vegetation.
The operation lead to conservation of dead ground vegetation and logging slash in buried at depths of 30 to 100 cm. The bulk density of upper horizons increases at this sites, pH decreases by 1-3 pH units (in comparison to control sites) as does microbiological activity. During first years after cutting reforestation is suppressed at these sites.
For the rest of the cutting area (without mechanical disturbance of ground and soil cover) soils changes result in temporary paludification and reforestation of forest vegetation. More intensive paludification processes develope in the soils of young cutting areas (5-10 years old) and lead to increasing spatial variation of morphological and chemical soil properties, gley processes activation, mobilization and segregation of Fe-compounds. Litter decomposition decreased under the hydromorphic regime resulting in decreasing capacity of forest litter and nitrogen depletion (Table 1).

Table 1. Changes of some characteristics of forest litter in chronosequences of clear-cuts

	Podzolic soils in silty loams			Podzols in lithologically discontinuous deposits		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
Thickness (cm)	5.5±0.8*	5.8±0.6	4.1±0.4	5.9±0.6	12.8±1.9	8.2±0.8
Litter density (g cm^3)	0.11±0.02	0.10±0.01	0.15±0.02	0.11±0.01	0.08±0.01	0.10±0.02
pH_{H2O}	4.3±0.1	4.4±0.1	5.0±0.2	4.1±1.0	4. 5±0.9	4.6±1.4
Ctot (%)	42.2±1.0	42.0±1.1	37.6±2.5	33.9±3.3	35.4±14.0	29.7±7.0
Ctot (1000 kg/ha)	25.53	24.36	23.12	23	33.9	25.0
Ntot (%)	1.64±0.09	1.45±0.05	1.61±0.08	0.86±0.23	1.04±0.6	1.1±0.4
Ntot (1000 kg/ha)	0.99	0.84	0.99	0.50	0.57	1.16
n	39	40	30	61	30	50

* confidence interval for mean value (p=0.05)

Soils of young cutting sites are also characterized by increasing chemical “aggressivity” and migratory ability of humic substances. In upper soil horizons we can observe an increase in hydrophilicity of alkali-soluble organic matter and water- and acid soluble organic compounds as well.
Changes in upper soil horizons under secondary succession after felling (with vegetation cover renewal) depend on texture (granulometric composition) of soil forming sediments. Soils formed in homogeneous sediments are characterized by a decrease in pH of forest litter and accumulation of biofilic components. Soil formed on lithologically heterogeneous sediments appear to have stronger changes in morphological and physicochemical properties.
Humic and fulvic acids extracted from soils a felling places are differentiated from substances of soils under native forests. Main distinctions are in elemental and amino acid composition of humic materials. At cutting sites the nitrogen content in humic acids is as much as 1.3-1.7 times higher as compared to those in native forest. Probably, changes in nitrogen concentration are explained by changes in the composition of forest waste.
Simplification of HA macromolecules structure in cut area soils results from temporary soil over-moisturing. This process is indicated by increasing H:C ratio (Table 2). Hydrolyzates of HAs extracted from ELhg horizons of cut area soils contain 154.9-145.1 g/kg amino acids which is as much as 4.5-4.8 times more compared to the same horizon of native forest soils. HAs extracted from the O horizon have 107.8-101.6 g/kg amino acids which is rather close to the values in native forest. Some residual hydromorphic the features remain even 36 years after tree logging as hardpan horizons and concretion aggregations in the upper soil.

Influence of oil and gas industry

Oil and gas industry impact on soil cover is connected with a considerable quantities of sites in the Komi

Republic (State 2009). Mining and oil and gas pipeline cause single-stage or repetitive impact on soil cover (Solntseva 1998).

Table 2. Elemental composition and molar ratios of humic substances (HSs) extracted from soils at chronosequences of clear-cutting (Podzolic soils in silty loams, Ust'Kulom district, Komi)

Plot	Horizon	Humic substances	C	N	H	O	H:C	O:C	C:N
			(g/kg)						
Plot 1	O	HAs*	536	28.0	40.6	396	0.90	0.55	22.32
	E	HAs	550	28.2	43.8	378	0.95	0.52	22.77
	O	FAs*	493	8.8	36.1	462	0.87	0.70	65.26
	E	FAs	483	18.1	43.3	456	1.07	0.71	31.08
Plot 2	O	HAs	526	33.8	44.2	396	1.00	0.57	18.15
	Ehg	HAs	566	43.4	57.1	334	1.20	0.44	15.19
	O	FAs	514	17.5	42.2	426	0.98	0.62	34.18
	Ehg	FAs	497	10.0	37.5	456	0.90	0.69	57.93
Plot 3	O	HAs	563	32.6	55.0	349	1.16	0.46	20.19
	E	HAs	510	47.6	47.2	396	1.10	0.58	12.49
	O	FAs	488	8.8	28.8	474	0.70	0.73	64.99
	E	FAs	474	14.9	47.3	464	1.19	0.73	37.01

* HAs – humic acids; FAs –fulvic acids.

Investigations of mining impact on northern and middle taiga subzone of the KR revealed the following:
1) Using of heavy tractors during first stages of construction of surface facilities for the well and pipeline routes, gasoline storage led to mechanical disturbances of native soils, deletion of upper (organogenic) horizons or burial under filled ground and creation of an anthropogenic landscape (Figure 1);

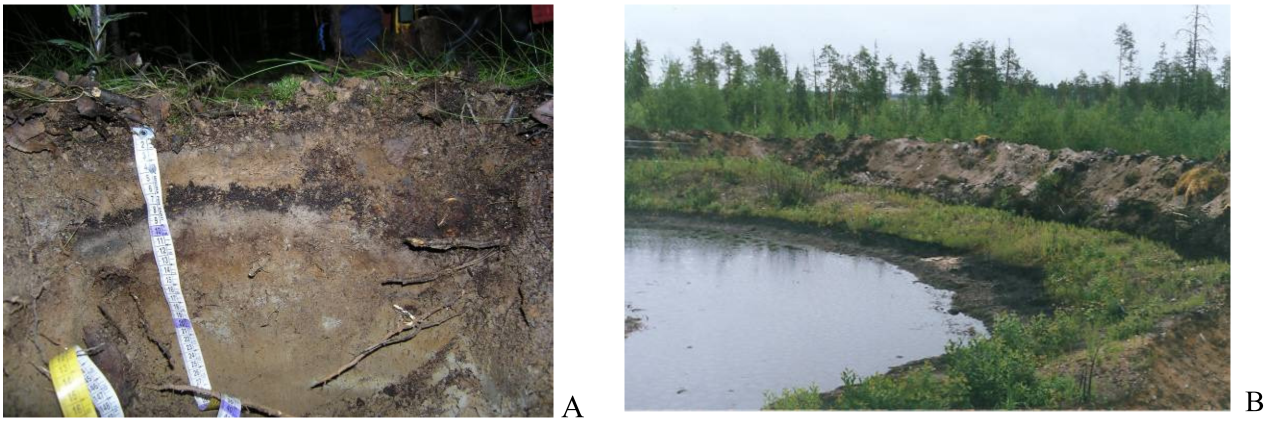

Figure 1. Human affected changes in podzolic soil profile (A) and local disturbances of soil and vegetation cover near gas producer (B).

2) Work of compressor station and well operation promotes hydrocarbons (mineral oil and oil products) pollution, easily soluble salts, heavy metals and other chemical components (acids, bases, surface-active substances) penetrate into soils and other landscape elements;
3) Carbon black, polycyclic aromatic hydrocarbons (including benzapirene) and sulphurous matters can enter the atmosphere under incomplete burning of accompanying gas and accumulate in upper soil horizons;
4) The Komi Republic is characterized by a humid climate with poorly-drained landscapes and swamp land domination. Chemical substances (hydrocarbons, acids, surface-active substance) inflow under such conditions are a very important factor for changes in morphological, physicochemical and biological soil properties. Consequences of this impact are determined by pollution duration, contaminant chemical characteristics and landscape peculiarities;
5) Contamination along gas and oil pipeline appears to be local and is usually registered visually as single spots.

Nowadays in the area of different oil and gas operations in the forest zone of the KR we can separate three degrees of soil degradation under human impact:
- ***low degree*** – integrity of soils are safe but some physicochemical properties changes
- ***middle degree*** – local disturbances of soil profile (upper soil horizons mainly) – mixing of soil horizons, burial some part of the soil, changes of primary soil process;
- ***high degree*** – total disturbance of soil profiles, removal of organogenic horizons, outcroping soil parent material.

Conclusion
In this article we present main reasons for changes in forest soils under human impact in the forest-covered area of the Komi Republic – one of Russian industrial regions. Timber industry plays a dominant role in forest soil disturbances. For middle taiga bioclimatic conditions, first years after logging are characterized by temporary soil over-moisturing. This changes not only morphological structure and physicochemical properties of cut site soils but also HS content and composition. Traces of temporary over-moisturing remain in soil 36 years after cutting. Change in tree species (spruce for mixed birch-spruce) causes a decrease in forest litter thickness and increases its density. Slow plant waste decomposition is due to excessive moisture (mostly during first after-logging years) which produces an increasing content of water- and acid-soluble organic compounds in soil organic matter (SOM). The hydrophilic part of SOM increases which accounts for its mobility.
Soils of logger-road and timber loading sites are transformed to a great extent. Physical changes in the soil of logger-roads occur down to a depth of 60 and down to 90 cm in timber loading sites. In the upper soil horizons of these of soils humus content is abruptly changed and biological activity is suppressed. Transformation soils under the influences of oil and gas extraction and pipeline reflect the quality of work, peculiarities of landscape and soils properties. The three soil degradation degrees under human impact were separated. Changes in podzolic and podzolic-boggy soils with low humus content and weak buffer value formed under middle and north taiga climatic conditions are substantial.

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References
Classification and diagnostics of Russian soils, V.V. Dokuchaev soil institute of RAAS (2004). 342p. (Moscow)
Forestry and forest resources of the Komi Republic (2000) (Eds GM Kozubov, AI Taskaev) 511 p. (Moscow)
Kanev VV, Mokiev VV (2004) Agro sod-podzolic soil of northeast Russian plain. 228 p. (Nauka: Saint-Petersburg)
Lal R (2005) Forest soils and carbon sequestration. *Forest Ecology and Management* **220**, 242–258.
Lodygin ED, Beznosikov VA, Chykov SN (2007) Structure functional parameters of humic substances of podzolic and boggy-podzolic soils. 145 p. (Nauka: Saint-Petersburg)
Rosnovskiy IN (2001) Soil disturbance under summer lumbering in West Siberia. *Lesovedenie* **2**, 22-26.
Rusanova GV (1987) Taiga soil micromorpholodgy. 152 p. (Nauka: Leningrad)
Soil and soil cover structure functional organization on the European northeast (2001) (Eds FR Zaidel'man and IV Zaboeva) 180 p. (Nauka: Saint-Petersburg)
Solntseva NP (1998) Oil mining and geochemical transformation of landscapes. 376 p (Moscow)
State report (2009) Environment state of the Komi Republic in 2008. 110 p. (Syktyvkar)
Theory and practice of soil chemical analysis (2005). 400 p (Moscow)
Zaboeva IV (1975) Soils and land resources of Komi ASSR. 350 p. (Syktyvkar)

Changes in soil chemistry following a watershed-scale application of wollastonite ($CaSiO_3$) at Hubbard Brook, New Hampshire, USA

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Abstract
Decades of acidic deposition in the northeastern United States is believed to have caused the loss of substantial amounts of calcium from forest soils. This process of 'calcium depletion' affected the chemistry of drainage waters in the region and may have impacted forest health. To study this phenomenon, we applied 45 Mg of wollastonite (1316 kg Ca ha^{-1}) to watershed 1 (W1) at the Hubbard Brook Experimental Forest, in New Hampshire, USA in October, 1999. Exchangeable Ca (1 M NH_4Cl) and soil pH increased significantly in the Oie and Oa horizons, and in the top 10 cm of the mineral soil, in samples collected 1, 3, and 7 years after treatment. Exchangeable acidity (1 M KCl) decreased significantly in the Oie and Oa horizons after treatment, but the effect in the upper mineral soil was not clear. Base saturation and effective cation exchange capacity (CEC_e) increased significantly after wollastonite application in all layers studied, primarily on the strength of the increased exchangeable Ca. We did not observe compensatory decreases in exchangeable Al, or other exchangeable cations, as initially hypothesized. Therefore, while wollastonite addition has improved the base status of W1 soils, it has not resulted in decreases in exchangeable Al.

Key Words
Soil acidity, acid rain, base saturation, calcium, cation exchange, liming.

Introduction
Acidic deposition, primarily in the form of sulfuric and nitric acid, has resulted in the acidification of soils and surface waters of the northeastern United States, and many other regions of the world. There is a growing consensus that this acidification has resulted in the depletion of available calcium from many base-poor soils (Likens *et al.* 1996; Driscoll *et al.* 2001). Soil calcium depletion may partly explain the sluggish response of surface waters in the northeastern United States to recent decreases in acidic deposition, and may also be related to declining forest health in the region (Warby *et al.* 2005; Hawley *et al.* 2006). To study these relationships, we initiated a watershed-level experiment in which calcium was added to the soil in the form of wollastonite ($CaSiO_3$), to replace the calcium believed to have been lost from the soil during the period of chronic acid rain. Unlike liming studies, we used calcium silicate because silicate weathering is the dominant weathering process in the base poor soils at our study site. The use of silicates also avoids the introduction of large amounts of alkalinity that accompanies the use of calcium carbonate lime.

This study is an ecosystem-level investigation of the response of vegetation, soils, fauna, and drainage waters to the addition of wollastonite. The objective of this presentation is to report the effects of the treatment on soil chemistry, particularly the acid-base status of the soils, as indexed by exchangeable Ca, Al, cation exchange capacity, base saturation, and pH. The results presented here extend the work of Cho *et al.* (In Press), which may be consulted for details of experimental design, sampling, and analysis.

Methods
Site Description
This work was done at the Hubbard Brook Experimental Forest, in the southern portion of the White Mountain National Forest in central New Hampshire, USA. The treated watershed – watershed 1 (W1) has an area of 11.8 ha and an elevation range from 488 m to 747 m. The soils at the HBEF are predominately Spodosols (Typic Haplorthods) derived from glacial till, and the average depths of the organic and the mineral soils are 7 cm and 50 cm, respectively. The dominant vegetation type on W1 consists of northern hardwood species (sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*) and yellow birch (*Betula alleghaniensis*)) on the lower 90 % of the watershed, and a montane boreal transition forest of red spruce (*Ricea rubens*), balsam fir (*Abies balsamea*) and white birch (*Betula papyrifera*) at high elevation. The climate at the HBEF is humid-continental, characterized by long, cold winters (average temperature for January is –9°C) and short cool summers (average for July is 10°C) with 1,400 mm of average annual

precipitation, approximately 30% of which falls as snow.
The experimental addition of wollastonite to W1 was designed to restore the base saturation of the soil to a level estimated to have existed at the advent of acidic deposition. Theoretically, the amount of Ca required to restore the overall base saturation of W1 soils from 10% to 19% was approximately 850 kg Ca/ha, equivalent to 30.2 tons of wollastonite over the area of W1. To account for potential losses or inefficiencies in wollastonite dissolution, a "safety factor" of 50% was added to the dose, resulting in an application of 45 tons of wollastonite, or 1,316 kg Ca/ha. The wollastonite was pelletized into 1.5 – 4 mm diameter pellets with a water-soluble binder, which allowed the pellets to disintegrate to individual particles (mean diameter 16 ㎛) in the presence of moisture after the manipulation (Peters *et al.* 2004). The application was made in October of 1999, after leaf fall, by helicopter, and was determined to be remarkably uniform across the watershed (Peters *et al.* 2004).

Soil sampling and analyses
Soil samples were collected at 100 randomly selected sites in W1 prior to (1998) and after (2000, 2002, and 2006) the treatment. Soil samples were collected from the Oi+Oe (Oie) and Oa layers, using 15 cm x 15 cm forest floor blocks. After the O horizon sampling, the upper mineral soil was sampled using a 5-cm diameter stainless steel corer. The depth of the cores was a maximum of 10 cm, but often less due to refusal of the corer by rocks.

The soil samples from the Oie horizons were oven dried at 80 ^{o}C to a constant weight, and ground in a Wiley mill. Samples from the Oa and upper mineral horizon were air dried, weighed, and sieved through 5-mm and 2-mm stainless steel screens, respectively. All soil samples were analyzed for pH_s (0.01 M $CaCl_2$). Exchangeable cations (Ca, Mg, K, Na, Al) were extracted with 1 M NH_4Cl. Exchangeable acidity was determined by titration of 1 M KCl extracts to a phenolphthalein end-point. Effective cation exchange capacity (CEC_e) was calculated as the sum of exchangeable acidity and exchangeable Ca, K, and Mg (Na was negligible in the extracts). Effective base saturation (BS_e) was computed as the sum of exchangeable bases, divided by the CEC_e and multiplied by 100.

Table 1. Changes in soil chemistry after wollastonite ($CaSiO_3$) addition to watershed 1 at the Hubbard Brook Experimental Forest, New Hampshire, USA.

Property	Horizon	Pre-Treatment	Post-Treatment		
		1998	2000	2002	2006
	Oie	5.62	24.4	34.7	33.9
Exch. Ca ($cmol_c$ /kg)	Oa	4.44	4.94	11.1	14.2
	Mineral	0.58	0.65	0.85	1.74
	Oie	1.13	0.84	0.87	0.86
Exch. Al ($cmol_c$ /kg)	Oa	6.90	7.07	5.29	3.89
	Mineral	6.19	5.26	6.02	5.22
	Oie	8.41	5.69	5.11	5.83
Exch. Acidity ($cmol_c$ /kg)	Oa	11.9	11.6	8.48	6.58
	Mineral	7.79	6.68	7.71	6.43
	Oie	16.2	32.7	43.6	44.4
CEC_e ($cmol_c$ /kg)	Oa	18.0	18.2	21.4	22.7
	Mineral	8.80	7.68	8.96	8.67
	Oie	48.7	78.6	86.1	86.9
BS_e (%)	Oa	32.9	35.8	56.0	71.0
	Mineral	12.1	13.1	14.3	25.8
	Oie	3.26	4.21	4.34	4.23
pH_s	Oa	3.03	3.24	3.48	3.62
	Mineral	3.35	3.47	3.44	3.50

Results
After wollastonite addition to W1, the pH and exchangeable Ca concentration in the soils increased significantly (Table 1). Exchangeable acidity and exchangeable Al decreased significantly, though the magnitudes of these decreases were less than the increase in exchangeable Ca. Consequently, wollastonite addition resulted in significant increases in both CEC_e and BS_e. Soil pH increased by nearly a whole pH unit in the Oie horizon, and 0.6 pH units in the Oa horizon.

The magnitude and timing of the changes in soil chemistry were strongly related to soil horizon. For example, seven years after treatment, exchangeable Ca had increased by a factor of 6 in the Oie horizon, compared to a factor of 3 in the Oa and mineral horizons. Most of the increase in exchangeable Ca in the Oie horizon occurred in the first year after treatment, whereas in the Oa and mineral horizons, it took 3 and 7 years, respectively, for the changes to be apparent (Table 1).

Discussion

The soil chemistry data suggest that the dissolution of the wollastonite added to W1 has resulted in an increase in the base status of soils which is progressive in time and space. Large increases in exchangeable Ca and base saturation occurred almost immediately in the Oie horizon, whereas increases in the Oa and mineral horizons occurred progressively later. These results are consistent with continuing dissolution of the added wollastonite and downward migration of the weathering products.

We had initially hypothesized that Ca released by the weathering of the wollastonite would displace Al and H from soil exchange sites. Our data indicate that this did occur to an extent. Exchangeable Al and acidity both decreased significantly after wollastonite addition. However, the magnitude of these decreases was much smaller than increases in exchangeable Ca. For example, in the Oa horizon, exchangeable Ca increased from 4.44 $cmol_c$ /kg prior to wollastonite, to 14.2 $cmol_c$ /kg seven years later (Table 1). In contrast, exchangeable acidity decreased by only half that amount, from 11.9 to 6.58 $cmol_c$ /kg. Because of this non-stoichiometric exchange, wollastonite addition resulted in a significant increase in the effective CEC in the soil.

The increase in CEC_e that we observed is consistent with increase in pH observed in W1 soils. Organic matter provides nearly all of the cation exchange capacity in soils at Hubbard Brook, and elsewhere in the region (Johnson 2002).

Conclusions

Wollastonite addition resulted in persistent increases in the base status of soils at Hubbard Brook. Our results suggest that wollastonite may be a good alternative to traditional lime as a potential amendment for acidified soils in the northeastern United States. Wollastonite appears to offer a long-lasting release of Ca without the alkalinity ‘shock’ produced by lime.

References

Cho Y, Driscoll CT, Johnson CE, Siccama TG (In press) Chemical changes in soil and soil solution after calcium silicate addition to a northern hardwood forest. *Biogeochemistry*

Driscoll CT, Lawrence GB, Bulger AA, Butler TJ, Cronan CS, Eagar C, Fallon Lambert K, Likens GE, Stoddard JL, Weathers KC (2001) Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. *BioScience* **51,** 180-198

Hawley GJ, Schaberg PG, Eagar C, Borer CH (2006) Calcium addition at the Hubbard Brook Experimental Forest reduced winter injury to red spruce in a high-injury year. *Canadian Journal of Forest Research* **36,** 2544-2549

Johnson CE (2002) Cation exchange properties of acid forest soils of the northeastern USA. *European Journal of Soil Science* **53,** 241-282

Likens GE, Driscoll CT, Buso DC (1996) Long-term effects of acid rain: response and recovery of a forest ecosystem. *Science* **272,** 244-246

Peters SC, Blum JD, Driscoll CT, Likens GE (2004) Dissolution of wollastonite during the experimental manipulation of Hubbard Brook Watershed 1. *Biogeochemistry* **67,** 309-329

Warby RAF, Driscoll CT, Johnson CE (2005) Chemical recovery of surface waters across the Northeastern United States from reduced inputs of acidic deposition: 1984-2001. *Environmental Science and Technology* **39,** 6548-6554

Changes in soil chemistry in the surroundings of wood ant (*Formica polyctena*) nests

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Abstract
Several previous studies reported on how the chemistry of the wood ant nest differs from the chemistry of the surrounding soil. In this contribution, we focused on changes in soil chemistry with distance from the nest. Soil samples 0-5cm deep were taken in a grid pattern at 1-19m from eight *Formica polyctena* nests in a spruce forest in the Czech Republic. Soil pH decreased with distance; pH decreased rapidly between 1 to about 8m and then decreased more slowly. The decrease in pH corresponded with the increase in organic matter content with distance from the nest because pH was negatively correlated with organic matter content. Organic matter content was significantly and positively correlated with available Ca and K, i.e., available Ca and K increased with distance from the nest. The changes in organic matter content, pH, and available Ca and K were apparently caused by ants collecting and using needles as building material.

Key Words
Biogeochemistry, basic cations, litter, nutrients.

Introduction
The group of wood ants includes dominant species of ants in boreal forest ecosystem (Dlusskij 1967). They are known for their large and long-lived colonies that may count several millions of individuals (Seifert 1996). Although the material used for nest building comes from the nest surroundings, soil properties of the nest are rather distinct from surrounding litter and soil (Dlusskij 1967; Frouz and Jilkova 2008; Jurgensen *et al.* 2008).

Through their activities, ants change physical, chemical and also biological properties of the soil (Boulton *et al.* 2003; Dlusskij 1967; Petal 1980). One of the changed soil properties is pH. pH affects nutrient availability to plants, compound solubility and also activity of microorganisms (Brady and Weil 2001). However, the range and cause of variation in pH between ant nests and their surroundings has not been completely revealed yet. In this study we tested the variance in pH and also other soil properties with the distance from the ant nests and we focused on influence of organic matter content and content of basic cations on pH.

Methods
Study site and sampling design
This study was conducted in a spruce forest (*Picea abies*) near Tabor (Czech Republic). Soil samples 0-5 cm deep were taken in a regular grid pattern (2 x 2m) in a rectangular area (4m wide and 20m long) in the close vicinity of the eight *Formica polyctena* nests. 33 soil samples were taken in each grid, 264 in total.

Quantifying of soil properties
Soil pH, organic matter content, available Ca, K, Mg and Na and humic acid composition were studied. Soil pH was measured in a 1:5 soil: water suspension by glass electrode. Basic cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) were extracted in 1:4 soil:Mehlich I solution (Mehlich 1953) and quantified by atomic absorption spectrophotometry with use of SpectrAA 640 at 420.7 nm (Varian, Inc. USA). Organic matter content was determined based on ignition loss after 5 hours in 600°C. Humic and fulvic acids were extracted for 12 h in 1 N NaOH (1:20 soil:NaOH); the samples then were diluted with deionized water (1:1), and humic and fulvic acid were measured using ELISA (Multi-Detection Microplate Reader, Synergy™ 2, BioTek) at 474 and 666 nm, respectively, and with NaOH diluted in deionized water (1:1) as a blank.

Statistics
For correlation of individual chemical parameters with distance from the nest, 2-D Euclidean distance between the nest centre (at ground level) and individual sampling points was calculated. Correlations were also calculated between individual chemical parameters measured and between residuals of the regression between pH and organic matter content.

Results
Soil pH decreases significantly with increasing distance from the ant nest (Figure 1a). This tendency is pronounced up to circa 8 m from the nest. Soil pH is significantly negatively correlated with soil organic matter content (Figure 1b), which shows significant positive correlation with distance from the nest (Figure 1c). This dependence is rather logaritmic, the distance the organic matter content most increases to is also circa 8 m from the nest. There are also other soil properties which have the influence on pH. If we take the residuals of correlation between pH and organic matter content, there is a negative correlation of these residuals with distance from the nest and content of humic and fulvic acids, while available Ca and K content show positive correlation with residuals (Table 1). With the distance from the nest change not only pH and organic matter content but also other soil properties, such as available Ca and K content and content of humic and fulvic acids (Table 1). Organic matter also influences contents of many other soil properties. There is a positive correlation between organic matter content and content of available Ca, Mg, Na and K and also content of humic and fulvic acids (Table 1).

Table 1. Correlation between individual parameters measured in soil surrounding eight *F. polyctena* nests. For each nest, 33 soil samples located 1 to 19 m from the nest were collected. The correlations are based on 264 samples. Correlation coefficients are shown only for significant correlations ($p<0.05$). Distance refers to distance from the nest. pH OM residuals refers to the variation in the correlation between pH and OM that was unexplained by organic matter content. A 474 is absorbance at 474 nm and corresponds to the content of humic acids. A 666 is absorbance at 474 nm and corresponds to content of fulvic acids.

	pH	OM	Ca	Mg	Na	K	A 474	A 666	pH OM residuals
Distance	-0.226	0.295	0.191			0.153	0.221	0.230	-0.122
pH		-0.385					-0.593	-0.533	0.917
OM			0.602	0.144	0.421	0.573	0.797	0.666	
Ca				0.221	0.446	0.704	0.410	0.292	0.196
Mg					-0.411	0.152	0.321	0.258	
Na						0.581			
K							0.369	0.279	0.189
A 474								0.903	-0.301
A 666									-0.292

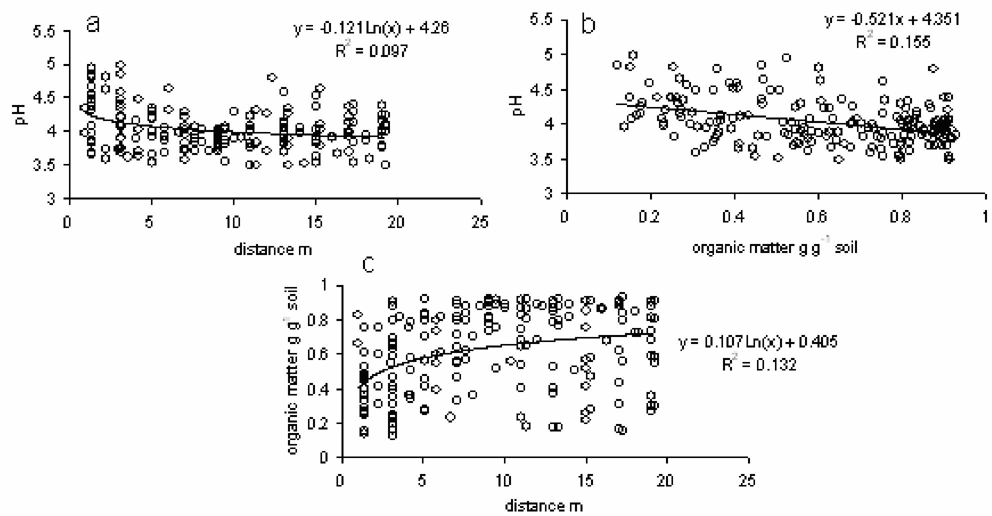

Figure 1. Relationships between soil pH, organic matter content, and distance from *Formica polyctena* nest. (a) A plot of pH on distance for all 264 samples; (b) A plot of soil pH on soil organic matter content for all 264 samples; and (c) A plot of soil organic matter content and distance for all 264 samples.

Discussion

It seems that pH changes are connected with changes in organic matter content. pH is strongly negatively correlated with organic matter content and so decrease in pH with distance from the nest seems to be caused by increasing organic matter content. Similar results shows Frouz *et al.* (2003). Although organic matter content explains a large portion of data variability, a significant portion of data variability remains unexplained. This portion correlates negatively with both humic and fulvic acid content and positively with basic cation (Ca and K) content. The negative correlation with humic acid is not surprising given that humus in coniferous soil is typically highly acidic (Brady and Weil 2001). Similarly, the positive correlation with basic cations is not surprising because such cations act in the cation exchange complex and thereby tend to increase soil pH (Brady and Weil 2001).

Content of basic cations strongly correlates with organic matter content and increases with increasing distance from the nest. Based on this study and previous literature data (Domisch *et al.* 2009; Frouz *et al*. 1997), we expect that cation enrichment in the nest and depletion in surroundings are given by two different mechanisms. We expect that nutrient enrichment in the nest is mostly caused by accumulation of food residues and excreta. Enrichment of the nest in close surroundings by basic cations can be the reason why these cations significantly explain residuals of pH after the effect of organic matter was removed. Depletion of nutrients in nest surroundings is connected with removal of needles, small branches and other litter particles which are used for nest building. Similarly these two mechanisms seem to affect pH around the nest.

Conclusion

Changes in pH seem to be caused by changes in organic matter content and content of basic cations and humic and fulvic acids. Ants are most probably responsible for these changes through their activities.

Acknowledgements

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References

Boulton AM, Jaffee BA, Scow KM (2003) Effects of a common harvester ant (*Messor andrei*) on richness and abundance of soil biota. *Applied Soil Ecology* **23,** 257-265.

Brady NC, Weil RR (2001) ‘The Nature and Properties of Soils.’ (Prentice-Hall: New York).

Dlusskij GM (1967) ‘Muravji Roda *Formica*.’ (Nauka: Moskva).

Domisch T, Finer L, Neuvonen S, Niemela P, Risch AC, Kilpelainen J, Ohashi M, Jurgensen MF (2009) Foraging activity and dietary spectrum of wood ants (Formica rufa group) and their role in nutrient fluxes in boreal forests. *Ecological Entomology* **34,** 369-377.

Frouz J, Jilkova V (2008) The effect of ants on soil properties and processes (Hymenoptera: Formicidae). *Myrmecological News* **11,** 191-199.

Frouz J, Santruckova H, Kalcik J (1997) The effect of wood ants (*Formica polyctena* Foerst.) on the transformation of phosphorus in a spruce plantation. *Pedobiologia* **41,** 437-447.

Jurgensen MF, Finer L, Domisch T, Kilpelainen J, Punttila P, Ohashi M, Niemela P, Sundstrom L, Neuvonen S, Risch AC (2008) Organic mound-building ants: their impact on soil properties in temperate and boreal forest. *Journal of Applied Entomology* **132,** 266-275.

Petal J (1980) Ant populations, their regulation and effect on soil in meadows. *Ekologia Polska – Polish Journal of Ecology* **28,** 297-326.

Seifert B (1996) ‘Ameisen: Beobachten, Bestimmen.’ (Naturbuch-Verlag: Ausburg).

Comparison of soil microbial biomass C, N and P between natural secondary forests and *Larix olgensis* plantations under temperate climate

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Abstract
Conversion of natural secondary forests (NSF) to mono-cultural *Larix olgensis* plantations (LOP) is a common forest management driven by an increasing demand for timber. To assess the impact of conversion of NSFs to LOPs on soil microbial properties under temperate climate, the microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP) were compared between NSF stands and LOP stands in Northeast China. The results indicated that the MBC, MBN and MBP were significantly lower in LOP stands than in NSF stands for both 0-15 cm and 15-30 cm soil layers. The percentage ratios of MBC, MBN, and MBP to soil organic C, total N or total P were significantly reduced in LOP stands; and they varied with time during the growing season significantly. The increase of microbial biomass in summer may be an important retention mechanism for conserving soil nutrients in the studied area. The above mentioned results suggest that NSF stands are better in conserving soil microbial biomass and nutrient than those of LOP stands.

Key Words
Microbial biomass carbon, nitrogen, P, Natural secondary forest, Larch plantation forest.

Introduction
Soil microbial biomass, both a source and sink of available nutrients for plants, plays a critical role in nutrient transformation in terrestrial ecosystems (Singh *et al.* 1989). Any changes in the microbial biomass may affect the cycling of soil organic matter. Thus, the soil microbial activity has a direct influence on ecosystem stability and fertility (Smith *et al.* 1993). Generally, microbial biomass can offer a means in assessing the soil quality in different vegetation types (Groffman *et al.* 2001).
Mixed broadleaved-Korean pine forest is one of the most important regional climax forest types in Northeast China, of which more than 70% have become natural secondary forest (NSF) after a century of timber exploitation (Zhu *et al.* 2007). To meet the growing demands for timber, many of the NSFs have been replaced by larch plantations (LOP) with fast-growing and high-yield reputation. Given the extensive coverage and economic value, the LOPs have in recent years attracted much attention in their role for contributing to ecosystem service as well as timber production (Zhu *et al.* 2007). However, decline in yield and soil fertility occurs in the LOPs. Generally, soil microbial biomass has been considered as the major indicator in the evaluation of soil restoration (Ross *et al.* 1982). Some researchers have found that soil microbial biomass decreased in the plantations in comparison with the natural forests in tropical and subtropical forest ecosystems (Behera and Sahani 2003). However, little information is available about the impacts NSFs and LOPs on soil microbial properties in the temperate forest ecosystems. In order to understand the mechanism of the yield and soil fertility decline in LOPs, and to maintain the long-term productivity of these forest soils, the impacts of forest conversion from NSF to LOP on soil microbial biomass under temperate climate were tested because the microbiological indicators have been applied by researchers in number studies of soil restoration in forest ecosystems (Wang and Wang 2007).

Methods
Site description and experimental design
The study was conducted at the Qingyuan Experimental Station of Forest Ecology, Institute of Applied Ecology, Chinese Academy of Sciences. The station is located in a mountainous region in the eastern Liaoning Province, Northeast China (41º51' N, 124º54' E, 500-1100 m a.s.l.). It is a continental monsoon type with a humid and rainy summer, and a cold and dry winter. The monthly mean temperature and precipitation in the growing season of 2008 are shown in **Table 1**. The brown forest soil belongs to Udalfs according to U.S. Soil Taxonomy.

The study site was originally occupied by primary mixed broadleaved-Korean pine forests until 1930s and subsequently subjected to decades of unregulated timber removal. A large fire that occurred in the early 1950s completely cleared off the original forests and the site was replaced by a mixture of naturally regenerating broadleaved native tree species (secondary forests). Since 1960s, patches of the NSFs were cleared for larch plantations. The sample plots were set up on three NSF stands and three LOP stands with ages 16- 44 years. The six stands have the same topographical features and are on soils developed from the same parental materials. In each of the stands, three 20 × 20 m plots were laid out in September 2006. The NSF plots consisted of *Juglans mandshurica*, *Quercus mongolica*, *Acer mono* and *Fraxinus rhynchophylla* in the tree layer, *A. triflorun*, *A. tegmentosum* and *Syringa amurensis* in the understory component. The LOP plots contain *Acer tegmentosum*, *A. pseudo-sieboldianum* and *Schisandra chinensis* in the shrub layer.

Table 1. Monthly mean air temperature and precipitation in the study area in 2008

Month	Apr	May	Jun	Jul	Aug	Sep	Oct
Temperature (Celsius degree)	9.90	13.04	16.38	20.27	18.07	16.09	11.55
Precipitation (mm)	58.6	161.3	158.3	264.4	185.1	31.8	19.2

Soil sampling and analyses

Soil samples were collected from the plots in April, July and September 2008, representing spring, summer and autumn seasons respectively. Litter was removed before sampling. Nine soil samples were randomly collected from 0 to 15 cm and 15-30 cm depths at each plot and mixed thoroughly to obtain a homogeneous sample for each soil depth. The mixed soil sample was divided into two parts. One was sieved through a 2-mm mesh immediately and stored at 4 ℃ until analysis for the estimation of microbial biomass C (MBC), microbial biomass N (MBN) and microbial biomass P (MBP). The other was air-dried and passed through a 0.25 mm sieve for the analyses of soil organic C (SOC), total N (TN) and total P (TP). SOC and TN were analyzed by dry combustion on a Vario EL elemental analyzer (Germany). The TP was determined following H_2SO_4-$HClO_4$ digestion (Olsen and Sommers 1982). MBC, MBN and MBP were determined by fumigation-extraction method (Vance *et al.* 1987).

Statistical analyses

All observed data are expressed on air-dry soil weight basis. Statistical analyses were performed by using the SPSS 11.5 for Windows. One-way ANOVA was performed by soil layers, and LSD's (least significant difference) test was applied post hoc to distinguish the differences of soil chemical properties between NSF and LOP. The three-way analyses of variance (three-way ANOVA) was used to compare the general effects of forest types, sampling seasons and soil layers on microbial biomass C, N and P.

Results

Soil chemical properties

SOC concentration was higher in the NSF than in the LOP for 0-15 cm soil layer (*P*<0.05), while concentrations of TN and TP did not significantly vary between the NSF and LOP stands for both 0-15 cm and 15-30 cm soil layers. The C/N, C/P and N/P ratios were significantly higher in NSF stands than those in LOP stands (*P*<0.05), and decreased with soil depth for both NSF and LOP stands (**Table 2**).

Table 2. Soil chemical properties in the natural secondary forest (NSF) and the *Larix olgensis* plantation (LOP)

Soil depth (cm)	Forest type	SOC (g/kg)	TN (g/kg)	TP (mg/kg)	C/N	C/P	N/P
0-15	NSF	50.5±6.2*	4.21±0.60	743±108	12.3±0.3*	70.2±3.2*	5.70±0.19*
	LOP	34.7±2.3	3.20±0.21	1010±85	10.9±0.2	35.2±1.8	3.23±0.14
15-30	NSF	23.4±3.8	2.18±0.40	645±113	11.1±0.3*	37.2±1.8*	3.35±0.13*
	LOP	24.0±2.4	2.38±0.22	918±73	10.0±0.2	25.9±1.1	2.59±0.09

SOC: soil organic C; TN: total N; TP: total P. Values shown in tables are means ± standard errors (n=9).
* Indicate significant differences between NSF stands and LOP stands at the corresponding depth at *P*=0.05 levels.

Soil microbial biomass

The concentrations of MBC, MBN and MBP were significantly greater in NSF stands than in LOP stands (**Figure 1**). There was significant seasonal variation in soil MBC for both the forest types (**Figure 1A**, *P*<0.05). However, there was no clear seasonal variations for MBN and MBP in both NSF and LOP stands (**Figure 1B, C**). Soil MBC concentration was significantly higher in summer than that in spring and autumn in the two soil layers for both the forest types (**Figure 1A**); whilst the MBN and MBP concentrations were not significantly different among the three seasons (**Figure 1B, C**).

The ratios of MBC/SOC, MBN/TN and MBP/TP were consistently higher in soils of the NSF stands than those of LOP in different seasons, with the exception of MBC/SOC, which was lower in spring in NSF stands (**Figure 2**). These ratios showed significant variations in sampling seasons both in NSF and LOP stands, which were higher in summer than those in spring and autumn (**Figure 2**).

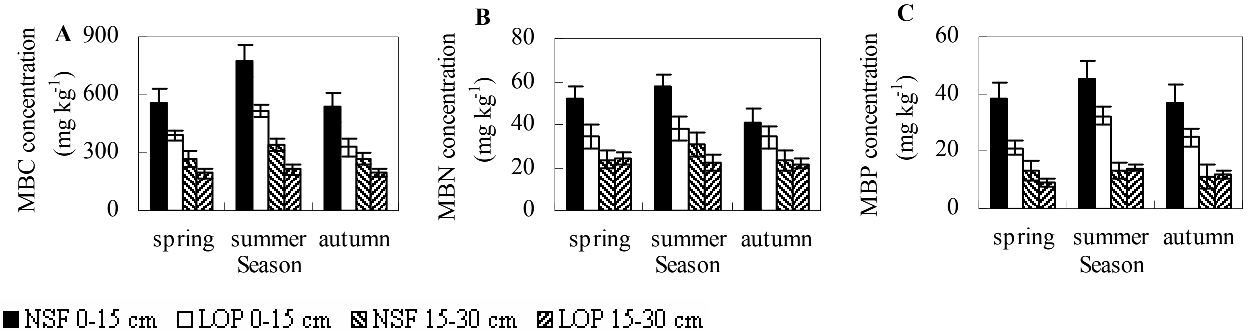

Figure 1. Microbial biomass C, N and P in soils of natural secondary forests (NSF) and *Larix olgensis* plantations (LOP) at different seasons. A: MBC, B: MBN, C: MBP (Vertical bars indicated the standard errors)

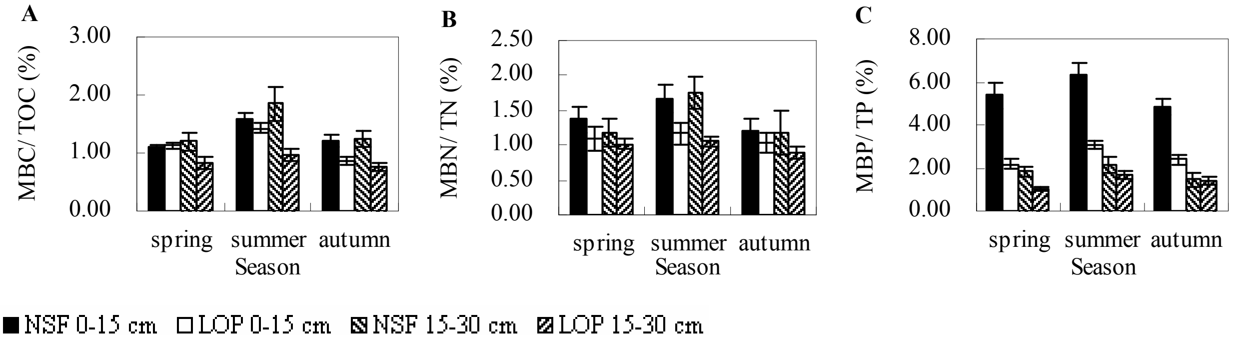

Figure 2. The ratios of MBC/SOC (A), MBN/TN (B) and MBP/TP (C) in the soils of natural secondary forest (NSF) and *Larix olgensis* plantation (LOP) at different seasons (Vertical bars indicated the standard errors)

Results from three-way ANOVA demonstrated that both forest types and sampling seasons had significant effects on MBC concentrations and the ratios of MBC/SOC, MBN/TN and MBP/TP. The soil MBN and MBP were significantly affected by forest types as well; but they were not significantly influenced by the sampling seasons (**Table 3**). The concentrations of MBC, MBN and MBP were all varied with the soil depth. There was a significant interaction between forest type and soil depth for MBC, MBN and MBP (**Table 3**).

Table 3. Results of three-factors ANOVA (soil depth, forest type and season) for microbial biomass and the ratio of microbial biomass to soil nutrients (P*<0.05, ***P*<0.01)**

Factors (*F*-ratios)	MBC	MBN	MBP	MBC/SOC	MBN/TN	MBP/TP
Forest type	30.19**	10.38**	10.83**	25.83**	10.63**	75.64**
Sampling Season	8.50**	2.21	2.66	14.77**	3.23*	6.83**
Depth	95.74**	45.27**	85.94**	1.25	0.58	157.08**
Forest × Season	0.65	1.01	0.51	2.12	1.22	1.39
Forest × Depth	4.62*	4.24*	8.80**	8.83**	0.11	41.23**
Season × Depth	3.23*	0.45	0.84	0.13	0.09	1.02
Forest × Season × Depth	0.05	0.38	0.01	1.30	0.17	0.11

Discussion and conclusions

Given the major differences in composition of tree species, we expected the differences in soil microbial biomass for the two forest types. The results that MBC, MBN, MBP, MBC/SOC, MBN/TN and MBP/TP ratios were significantly higher in NSF stands than those in LOP stands suggest the advantage of NSF in conserving soil fertility. Generally, soil microbial biomass depends on soil organic matter as substrate; therefore, the decrease of SOC will cause the reduction of soil microbial biomass (Chen *et al.* 2005). Thus, the main factor that induced the higher concentrations of MBC, MBN and MBP in NSF stands seems to be the greater availability of organic matter in NSF stands. The reasons for the decline of SOC in LOP stands may be explained as follows: firstly, poor site preparation practices such as removal of litter and ploughing before planting, which resulted in rapid and large loss of soil organic matter. Secondly, NSF stands contain more tree species than those in LOP stands; and the number of tree species affect the availability and biochemical composition of organic matter inputs into soil (Leckie *et al.* 2004). Thirdly, the decomposition of litter in LOP stands was relatively slower in comparison with NSFs (Liu *et al.* 1998).

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The MBC/SOC ratio or microbial quotient has been widely used as an indicator of the changes in organic matter status due to alterations of soil conditions (Sparling 1992). In our study, the ratio of MBC/SOC was lower in LOP than in NSF stands for both 0-15 cm and 15-30 cm soil depths, suggesting the decreases of organic matter in LOP stands (**Table 2**). The lower MBN/TN and MBP/TP in LOP stands supported the conclusion obtained by Joergensen and Scheu (1999), i.e., the decline of MBC/SOC meant the decrease of available organic matter in soils. These results are consistent with the conclusion of Wang and Wang (2007) who reported that microbial quotient decreased in pure coniferous plantation in the subtropical forest ecosystem.

The two forest types investigated exhibited significant seasonal variation in soil MBC, but not in soil MBN and MBP in Northeast China. In both NSF and LOP stands, MBC concentration was higher in summer, indicating the more immobilization of nutrients by the microbial biomass from the decomposing litters. Furthermore, the soil temperature and moisture were favourable for the microbial growth during the summer (Table 1). This result was similar to the previous studies in temperate forests (Bohlen *et al.* 2001). The result of less sensitive to seasonal changes in MBN and MBP obtained in our study was consistent with Chen et al. (2006) who reported that the seasonal patterns were less obvious in Mongolian pine plantations at the Keerqin sand lands (42º43' N, 122º22' E), China. This is because the potential for N and P immobilization-mineralization by microbial biomass is stable during the growing season in temperate forests.
In summary, the concentrations of MBC, MBN and MBP, and the ratios of MBC/SOC, MBN/TN and MBP/TP reduced significantly in LOP stands; which suggested that the NSF was better to conserve microbial activity than the LOP in Northeast China.

References

Behera N, Sahani U (2003) Soil microbial biomass and activity in response to *Eucalyptus* plantation and natural regeneration on tropical soil. *Forest Ecology and Management* **174,** 1-11.

Bohlen PJ, Groffman PM, Driscoll CT, Fahey TJ, Siccama TG (2001) Plant-soil-microbial interactions in a northern hardwood forest. *Ecology* **82,** 965-978.

Chen FS, Zeng DH, Zhou B, Singh AN, Fan ZP (2006) Seasonal variation in soil nitrogen availability under Mongolian pine plantations at the Keerqin Sand Lands, China. *Journal of Arid Environments* **67,** 226-239.

Chen TH, Chiu CY, Tian GL (2005) Seasonal dynamics of soil microbial biomass in coastal sand dune forest. *Pedobiologia* **49,** 645-653.

Groffman PM, McDowell WH, Myers JC, Merriam JL (2001) Soil microbial biomass and activity in tropical riparian forests. *Soil Biology & Biochemistry* **33,** 1339-1348.

Joergensen RG, Scheu S (1999) Depth gradients of microbial and chemical properties in moder soils under beech and spruce. *Pedobiologia* **43,** 134-144.

Leckie SE, Prescott CE, Grayston SJ (2004) Forest floor microbial community response to tree species and fertilization of regenerating coniferous forests. *Canadian Journal of Forest Research* **34,** 1426-1435.

Liu SR, Li XM, Niu LM (1998) The degradation of soil fertility in pure larch plantations in the northeastern of China. *Ecological Engineering* **10,** 75-86.

Olsen SR, Sommers LE (1982) Phosphorus. In 'Methods of Soil Analysis - Part 2. Chemical and Microbiological Properties'. (Eds AL Page, RH Miller, DR Keeney) pp. 403-410.

Ross DJ, Speir TW, Tate KR, Cairns A, Meyrich KF, Pansier EA (1982) Restoration of pasture after topsoil removal: effect of soil carbon and nitrogen mineralization, microbial biomass and enzyme activities. *Soil Biology & Biochemistry* **14,** 575-81.

Singh JS, Raghubanshi AS, Singh RS, Srivastava SC (1989) Microbial biomass acts as a source of plant nutrients in dry tropical forest and savanna. *Nature* **338,** 499-500.

Smith JL, Papendick RI, Bezdicek DF, Lynch JM (1993) Soil organic matter dynamics and crop residue management. Soil Microbial Ecology. (Ed FB Jr) pp. 65-94.

Sparling GP (1992) Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Australian Journal of Soil Research* **30,** 195-207.

Vance ED, Brookes PC, Jenkinson DS (1987) An extraction method for measuring soil microbial biomass C. *Soil Biology & Biochemistry* **19,** 703-707.

Wang QK, Wang SL (2007) Soil organic matter under different forest types in Southern China. *Geoderma* **142,** 349-356.

Zhu JJ, Mao ZH, Hu LL, Zhang JX (2007) Plant diversity of secondary forests in response to anthropogenic disturbance levels in montane regions of northeastern China. *Journal of Forest Research* **12,** 403-416.

Comparison of soil water repellency and sorptivity between an *Acacia caven* (highly-perturbed) and *Cryptocarya alba* (slightly-perturbed) dominated ecosystem

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Abstract
Schlerophyll ecosystems are the predominant vegetation type in Central Chile having a long history of degradation by fire, cultivation, firewood extraction and grazing, among others. In order to test soil organic carbon (SOC) mediated reductions in water repellency from a slightly-disturbed *Cryptocarya alba* to a highly-disturbed *Acacia caven* site, we compared intact soil aggregates and sieved soil samples from both situations using a micro-infiltrometer. We found a significantly greater concentration of SOC and repellency index (R) under the slightly-disturbed *C. alba* compared to the highly-disturbed *A. caven* site. We also found a significant correlation between these two parameters for intact soil aggregates. It seems that SOC rather than disturbance per se, could be the main factor mediating water repellency. Water repellency did not significantly decrease in sieved- compared to intact-samples, suggesting that water repellency is independent of soil structure.

Key Words
Water repellency, sorptivity, disturbance, schlerophyll ecosystems.

Introduction
Schlerophyll ecosystems cover around 345 thousands (2.6%) of the 13.4 million ha of native forests in Chile, being the predominant vegetation type in Central Chile where, the greatest proportion of the population lives, emphasizing the need for its conservation. The development of the rural settlements has had a negative effect on Mediterranean ecosystems, as a result of using fire before cropping, firewood extraction and overgrazing practices. These practices have resulted in soil erosion and soil degradation. Protection of previously over-exploited areas has permitted the recovery of some vegetation and soil processes. Here arises the question whether or not soil recovery is taking place and at what extent. The aim of this study was to compare water repellency and sorptivity (S) from intact and sieved soil samples from an *Acacia caven* (highly-perturbed) and *Cryptocarya alba* (slightly-perturbed) dominated ecosystem. We hypothesize that soil repellency is driven by soil organic carbon, so that, the slightly-perturbed site would exhibit greater repellency than the highly-perturbed site for both intact and sieved soil samples.

Material
The study was carried out in the National Reserve "Roblería del Cobre de Loncha", located in Alhué, Central Chile (Figure 1). The climate is calid-template (Cs) with a prolonged dry season from 6 to 8 months according to the classification of Koeppen and Fuenzalida (U. de Chile 2007). Rainfall is concentrated during the winter months (June to August) with an annual average of 503 mm (Santibañez and Uribe 1993). Two sites were selected, representing two conditions with contrasting disturbance levels:

Abandoned agriculture: these sites are characterized by historical extraction of firewood followed by agricultural crops (mainly wheat). After disturbance ending around thirty years ago, a perennial cover of around 10% was gradually established with the legume tree *Acacia caven* and some schlerophyll species such as *Quillaja Saponaria* and *Lithraea caustica*. Common annual grasses from the genus *Melica*, *Nasella* and *Bromus* sp, among others, are the dominant cover during winter, and dying by the end of spring.

Slightly-disturbed schlerophyll forest: These sites are dominated by the schlerophyll species *Cryptocarya alba* (Peumo), *Lithraea caustica* (Litre), *Quillaja saponaria* (Quillay), and *Peumus boldus* (Boldo). These are second growth-coppices brought about by fire and firewood extraction 30 o more years ago. Nowadays these are slightly disturbed by occasional cattle grazing.

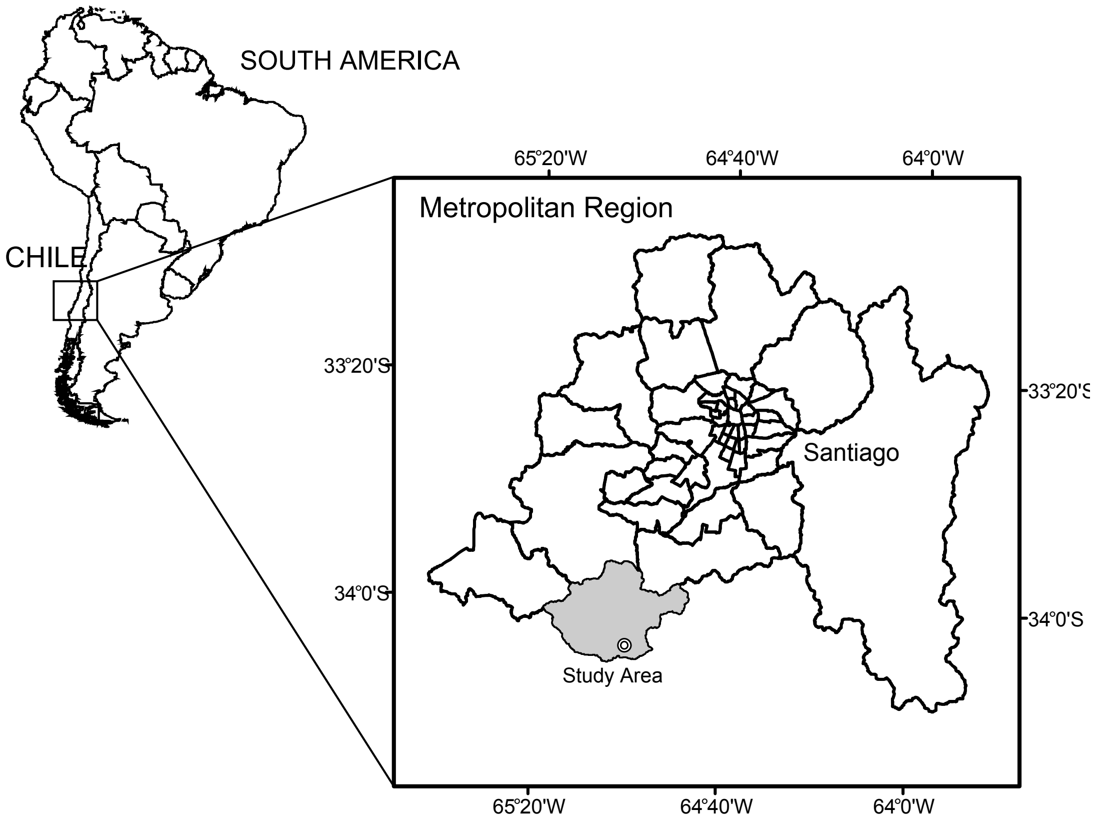

Figure 1. Location of the National Reserve "Roblería del Cobre de Loncha", Alhue, Central Chile.

Methods

In each of the two sites, soil samples of about 700 g were randomly extracted from five points, at soil depths of 0-10 and 10-20 cm. Samples were air-dried and kept in HD polyethylene boxes until water repellency measurements were taken. Repellency was measured following Hallet and Young (1999), over soil aggregates and sieved soil samples. Basically, water repellency and sorptivity are determined by the Leeds-Harrison *et al*. (1994) infiltrometer, which compares curves of infiltration versus time for water and ethanol. Soil organic C was determined by wet combustion and colorimetry. Bulk density of soil aggregates was determined by volume displacement of previously sealed aggregates. Soil porosity was calculated as a function of soil bulk density and assuming a particle density of 2.65 g cm^3.

All analyses were undertaken at the three level using the R language (R Foundation for Statistical Computing, Vienna, Austria). Variables were tested for normality and homogeneity of variance and transformations were made as necessary to meet the underlying statistical assumptions of the models used. The main effects of disturbance on soil repellency and sorptivity variables were examined by analysis of variance. Tukey's least significant difference test was used to distinguish among individual means where applicable with a confidence level of $P \leq 0.05$. Differences in the slopes and the intercepts in the relationships between soil repellency and SOC were tested for significance between *A. caven* (highly-disturbed) and *C. alba* (slightly disturbed) using analysis of covariance.

Results

Highly-disturbed (*Acacia caven*) and slightly-disturbed (*Cryptocarya alba*) sites were compared for soil porosity, soil organic carbon, water sorptivity, ethanol sorptivity, and the repellency index (Table 1). Porosity, organic carbon, ethanol sorptivity, and the repellency index significantly decreased from the slightly- to the highly-disturbed site ($P < 0.05$). In other words disturbance brought about drastic reductions in all these characteristics. Water sorptivity was not significantly different between the highly-disturbed and the slightly-disturbed sites except for the sieved samples taken from 10-20 cm depth. Soil porosity and SOC consistently decreased with soil depth for both intact and sieved samples. The same trend was observed for the repellency index. Water and ethanol sorptivity were much greater for the sieved than for the intact soil samples.

Table 1. Comparison of physical and chemical properties between an *Acacia caven* (highly-disturbed) and *Cryptocarya alba* (slightly-disturbed) dominated ecosystem. Different lower-case letters indicate significant differences at *P* < 0.05 between the highly- and the slightly-disturbed site.

	Soil depth (cm)		Porosity	Organic carbon (%)	Water sorptivity ($mm/s^{1/2}$)	Ethanol sorptivity ($mm/s^{1/2}$)	Repellency index, R
Soil aggregates	0-10	*C. alba*	0.57 ±0.02 a	6,80 ±0,71 a	0,96 ±0,31 a	1,67 ±0,06 a	4,48 ±1,18 a
		A. caven	0.38 ±0.03 b	1,76 ±0,25 b	1,25 ±0,50 a	0,78 ±0,17 b	1,61 ±0,46 b
	10-20	*C. alba*	0.53 ±0.04 a	3,90 ±0,76 a	1,26 ±0,18 a	1,70 ±0,13 a	2,73 ±0,27 a
		A. caven	0.34 ±0.03 b	0,91 ±0,06 b	1,03 ±0,37 a	0,65 ±0,12 b	1,42 ±0,15 b
Sieved soil samples	0-10	C. alba	0.68 ±0.01 a	6,80 ±0,71 a	1,80 ±0,19 a	2,58 ±0,14 a	2,86 ±0,22 a
		A. caven	0.60 ±0.01 b	1,76 ±0,25 b	2,06 ±0,09 a	1,58 ±0,13 b	1,50 ±0,12 b
	10-20	C. alba	0.63 ±0.01 a	3,90 ±0,76 a	2,76 ±0,09 a	2,48 ±0,05 a	1,77 ±0,08 a
		A. caven	0.58 ±0.01 b	0,91 ±0,06 b	1,69 ±0,16 b	1,85 ±0,15 b	2,24 ±0,34 a

We found a significant linear correlation between R and SOC ($P < 0.001$) for intact samples but not for sieved samples ($P = 0.11$) (Figure 2). Slopes and intercepts of these linear relationships for intact samples were not influenced by disturbance, suggesting that differences in repellency between the *A. caven* and *C. alba* sites were well explained by their differences in soil organic C for intact soil aggregates.

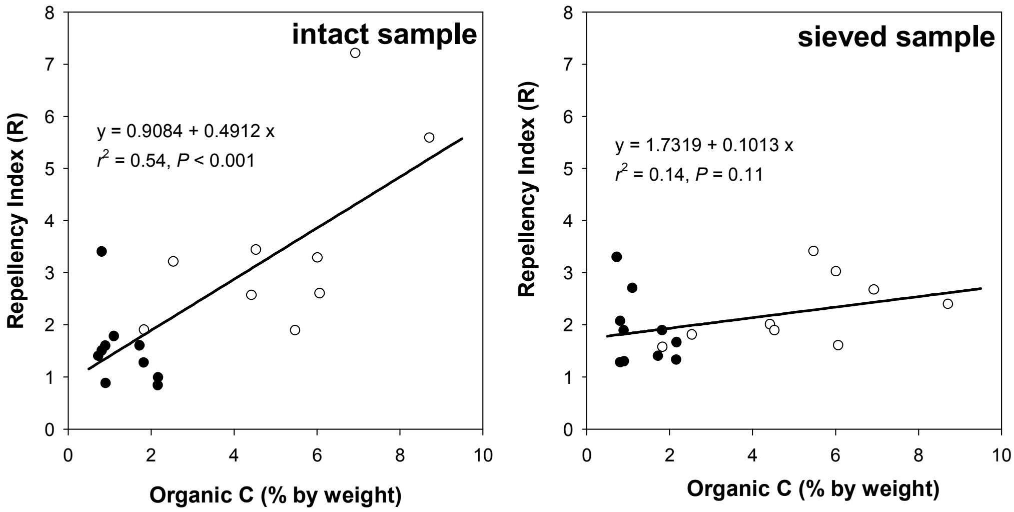

Figure 2. Relationship between measured soil organic C and repellency index for intact and sieved samples.

Conclusions

Water sorptivity did not exhibit significant differences between the *A. caven* (highly-disturbed) and the *C. alba* (slightly-disturbed) sites, although differences were found for ethanol sorptivity. Such difference suggests that there is a limiting factor to water infiltration in the slightly-disturbed site of *C. alba*. Sieved samples showed greater sorptivity which might be explained by the greater porosity in the sieved- compared to the intact-sample.

We found a significantly greater concentration of soil organic carbon and repellency index in the slightly-disturbed (*C. alba*) compared to the highly-disturbed (*A. caven*) site. We also found a significant correlation between these two variables for intact samples (but not for sieved samples). Therefore soil organic carbon, rather than disturbance *per se*, may be the main factor mediating water repellency.
Water repellency did not significantly decrease in sieved- compared to intact-samples, suggesting that water repellency is independent of soil structure.

Acknowledgements

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References

Santibañez F, Uribe J (1993) Atlas agroclimático de Chile. Regiones Sexta, Séptima, Octava y Novena. Universidad de Chile, Santiago, Chile. 99p.

U. de Chile (2007) Profundización de la línea de base ambiental y ecológica del sector de mayor valor ecológico del cordón de Cantillana. (CONAMA-GEF-PNUD. Proyecto “Conservación de la Biodiversidad en los Altos de Cantillana, Chile”) 257p.

Hallet P, Young I (1999) Changes to water repellence of soils aggregates caused by substrate-induced microbial activity. *European Journal of Soil Science* **50**, 35-40.

Leeds-Harrison P, Youngs E, Uddin B (1994) A device for determining the sorptivity of soil aggregates. *European Journal of Soil Science* **45**, 269-272.

Current organic carbon stock in topsoil of forest land in Japan

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Abstract
To evaluate the current organic carbon stock in forest topsoil in Japan, a systematic survey has been carried out since 2006. As of the end of 2008, organic carbon densities in the first 0.3 m of soil had been measured at 1,200 forest sites. Organic carbon density ranged from 0.34 to 19.51 kg/m^2 for mineral soils. The combination of wide variation in temperate conditions reflected by mean annual temperature, the unstableness of soil material implied by slope angles, and the widespread distribution of volcanic ejecta are supposed to create the complicated distribution of soil organic carbon stock in Japanese forests. The mean organic carbon density was 7.05 ± 3.03 kg/m^2 (mean ± SD) for all samples including organic soil. This value is lower than a previous estimate, possibly due to differences in the method of estimating the coarse fragment volume in the soil mass and the method of dry bulk density measurement.

Key Words
Forest soil, Japan, organic carbon stock, systematic sampling.

Introduction
A strategic survey to obtain a soil carbon inventory of Japan's forest sector and evaluate the current soil carbon stock was launched in 2006. The goal was to obtain a comprehensive survey of all forestlands in Japan over 5 years, from 2006 to 2011 (Takahashi and Morisada 2008). The layout of the survey sites and soil sampling method were established considering the effect of soil variability on organic carbon stock evaluation, as soil variability can cause wide differences in estimations of soil carbon stock (Swift 2001). To avoid sample bias, survey sites were systematically selected from the plots of the Forest Resources Monitoring Survey conducted by the Forestry Agency, Government of Japan (Takahashi and Morisada 2008). The Monitoring Survey plots were set up at 4 × 4-km grid intervals to cover the whole forested area of Japan, and every fifth plot was designated as a special plot (Hirata *et al.* 2009). The survey sites for the current project correspond to the special plots of the Monitoring Survey and represent one-fifth of the Monitoring Survey plots. The current project will survey approximately 3,000 sites located about every 80 km^2 throughout the forestland of Japan. The project is expected to advance understanding of soil variability at the national scale. Systematic soil sampling has been performed to avoid sampling bias (Takahashi and Morisada 2008). By the end of 2008, measurement of organic carbon densities in topsoil had been completed at half of the planned survey sites. The surveyed sites appear to evenly cover forested land, and the results obtained to date can offer insight into the distribution of organic carbon stocks in forest soils in Japan. In this paper, we present interim results from the first 3 years of the survey.

Methods
Measurement of soil organic carbon density
Briefly, the field sampling method (Forest Sinks Working Group 2007a) was as follows. Soil was sampled at four systematically designated points at a Monitoring Survey plot. The depth interval of sampling was fixed to 0.3 m. Soil samples for carbon content measurement were taken from soil depths of 0–0.05, 0.05–0.10, and 0.15–0.30 m after collecting litter samples from the soil surface. Undisturbed soil samples for bulk density measurement were taken from the same depth intervals using a 400-mL soil-sampling cylinder (100 cm^2 × 4 cm). In the case that a cylinder could not be used, an excavating method was applied. The volume ratio of coarse fragments (>2 mm) was estimated by eye using a chart (Oyama and Takehara 1967) for comparison.

The methods of sample analysis (Forest Sinks Working Group 2007b) and calculation of soil organic carbon density in each plot were as follows.
The bulk density of fine earth (BD) was calculated by
$BD = (Sw - Gw - Rw) / V$,
where Sw is the oven-dry weight of the sample, Gw is oven-dry weight of coarse fragments in the sample,

Rw is oven-dry weight of roots in the sample, and V is the sample volume.
The carbon concentration of fine earth was determined by a dry combustion method.
The soil organic carbon density for a sampling point (SOC, C kg/m^2) was estimated as
$SOC = \Sigma OC_i \times BD_i \times D_i \times (1 - S_i)$,
where OC_i is the concentration of organic carbon in layer i, BD_i is the bulk density of layer i, D_i is the thickness of layer i, and S_i is the volume ratio of coarse fragments in layer i. The mean density of sampling points in the plot was used as the representative value of soil organic carbon density in each plot.

Examination of the distribution of organic carbon stocks
Correlations of organic carbon density by plot with the temperature condition, slope condition, and parent material were examined considering major characteristics of the pedogenesis of Japanese soils (Kyuma 1990). Mean annual temperature estimated from digital climate data (Japan Meteorological Agency 2002) represented the temperature condition of a plot. The slope condition was given by slope data for each plot derived from the site description of the Monitoring Survey report (Forestry Agency unpublished). The surface geology estimated from digital geology data (Wakamatsu *et al.* 2005) was used to identify the parent material. Data from 1,203 sites at which the soil organic carbon density was plotted in three or four of the four sampling points were used for this study.

Results

The soil organic carbon density of plots ranged from 0.34 to 19.51 kg/m^2 for mineral soils. The organic carbon density of organic soil was 25.0 kg/m^2 (n = 1). Regional differences were found in the distribution of organic carbon density. In general, the organic carbon density of forest topsoil was high in the eastern region and low in the western region. This regional difference in carbon density corresponded to the relationship between carbon density and the temperature condition. Soil carbon density tended to increase with the decrease in mean annual temperature, but the correlation between carbon density and mean annual temperature was not strong (Figure 1). Soil carbon density tended to be low in steeply sloped areas (Figure 2). Considering the influence of slope will provide better evaluations of the organic carbon stock in Japanese forestland because about 30% of forests are located on slopes steeper than 30 degrees (Forestry Agency 1968). The carbon density also differed according to the geologic age of the land surface (Figure 3). The widely distributed volcanic ejecta in Japan clearly influence the organic carbon stock in topsoil. However, given the present limited knowledge of the areal and depth extent of volcanic ejecta, it is difficult to distinguish the influence of volcanic ejecta on organic carbon stock at the nationwide scale.

The combination of wide variation in temperate conditions shown by mean annual temperature, the unstableness of soil material implied by slope degrees, and the wide distribution of volcanic ejecta are supposed to create the complicated distribution of soil organic carbon stock in Japan's forests.
The present organic carbon density was estimated to be 7.05 ± 3.03 kg/m^2 (mean ± SD) for all samples including organic soil. This estimate is lower than a previous estimate by Morisada *et al.* (2004). The difference between the two estimates may be attributable to differences in the method of estimating the volume of coarse fragments. Volume of coarse fragments was estimated in the field for the present survey, but volume of coarse fragments in the previous estimate was estimated from the abundance of stone in field descriptions (Morisada *et al.* 2004). Differences in the method of dry bulk density measurement may also have contributed to the difference between the estimates. Sampling strategy also might effect on the estimation of soil organic carbon stock. Systematic sampling was performed in the present survey, whereas samples in the previous estimate were judgement sampling (Petersen and Calvin 1965).

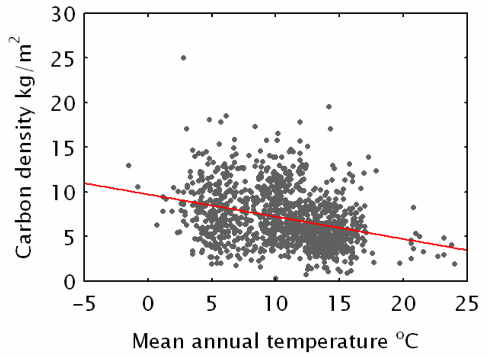

Figure 1. Relationship between mean annual temperature and organic carbon density.

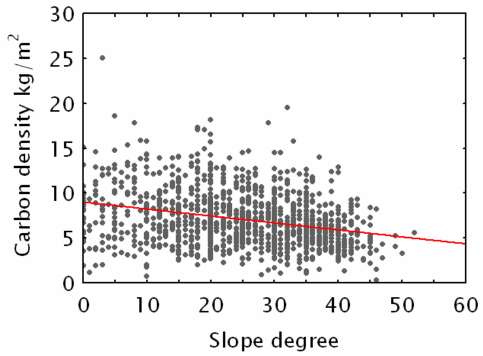

Figure 2. Relationship between slope degree and organic carbon density.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

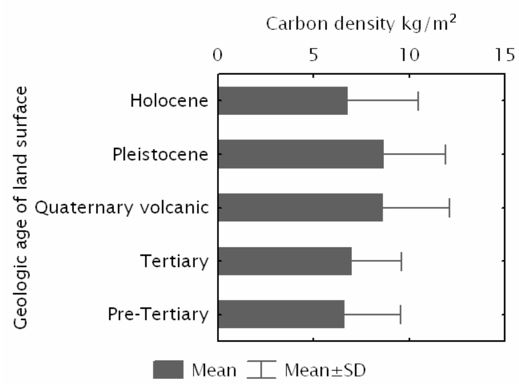

Figure 3. Carbon density by the geological conditions of the plots.

Conclusion

The present organic carbon stock in forest topsoil in Japan was estimated from the results of a systematic soil survey. Wide variation in temperature, unstable soil materials, and widespread distribution of volcanic ejecta are supposed to create the complicated distribution of soil organic carbon stock in Japanese forests.

References

Forestry Agency (1968) ‘Forest Resources of Japan’. (Rinya-Kyosai-Kai: Tokyo) (in Japanese).

Forest Sinks Working Group (2007a) ‘Manuals for inventory of soil carbon stock in Japanese forest (1) Field Survey’. (Forestry and Forest Products Research Institute: Tsukuba) (in Japanese). www.ffpri.affrc.go.jp/labs/fsinvent/manural/manualdown.

Forest Sinks Working Group (2007b) ‘Manuals for inventory of soil carbon stock in Japanese forest (2) Analytical Methods’. (Forestry and Forest Products Research Institute: Tsukuba) (in Japanese). www.ffpri.affrc.go.jp/labs/fsinvent/manural/manualdown.

Hirata Y, Imaizumi Y, Masuyama T, Matsumoto Y, Miyazono H, Goto T (2009) In ‘National Forest Inventories’. (Eds E Tomppo, T Gschwanter, M Lawrence, RE McRoberts) pp. 333-340 (Springer: Heidelberg Dordrecht London New York).

Japan Meteorological Agency (2002) ‘Mesh Climatic Data of Japan’ (CD-ROM).

Kyuma K (1990) Outline of the pedogenesis of Japanese soils. In ‘Explanatory book for soil map of Japan 1:1,000,000'. (Eds The Committee for Soil Classification and Nomenclature, The Group of Japanese Pedologists) pp.3-6 (The Group of Japanese Pedologists: Tsukuba).

Morisada K, Ono K, Kanomata H (2004) Organic carbon stock in forest soils in Japan. *Geoderma* **119,** 21-32.

Oyama M, Takehara H (1967) Revised Standard Soil Color Charts. (Fujihira Industry Co.: Tokyo).

Petersen RG, Calvin LD (1965) Sampling. In ‘Methods of Soil Analysis, Part 1’ (Ed CA Black) pp.54-72 (American Society of Agronomy: Madison).

Swift RS (2001) Sequestration of carbon by soil. *Soil Science* **166,** 858-871.

Takahashi M, Morisada K (2008) Nation-wide survey of carbon stock in forest soils in Japan. *Japanese Journal of Soil Science and Plant Nutrition* **79,** 109-111. (In Japanese).

Wakamatsu K, Kubo S, Matsuoka M, Hasegawa K, Sugiura M (2005) ‘Japan Engineering Geomorphologic Classification Map’. (CD-ROM, University of Tokyo Press: Tokyo, product serial number JEGM0431).

Determinants of soil organic matter chemistry in maritime temperate forest ecosystems

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Abstract
The influences of ecosystem properties on the chemical complexity of soil organic matter (SOM) remain poorly understood. This study addresses the composition of NaOH-extracted SOM from maritime temperate forest sites in Flanders (Belgium) by pyrolysis-GC/MS. Pyrolysis-products were correlated to site variables including dominant tree species, management of the woody biomass, site history, soil properties, total carbon stocks and indicators for microbial activity. Despite a typical high inter-correlation between these site variables, the influence of the dominant tree species is prominent, as is a strong correlation to available nutrients. In nutrient-poor forests with low litter quality, the decomposition of relatively recalcitrant compounds appears hampered. Former heathland vegetation still had a profound influence on extractable-SOM chemistry of young pine forests.

Key Words
Soil organic matter composition, temperate forest soils, pyrolysis-GC/MS, environmental factors.

Introduction
While the influence of climate, vegetation, management and abiotic site factors on total C budgets and turn-over is intensively assessed, high-resolution studies that elaborate on the general relations between these ecosystem properties and the chemical composition SOM are much more scarce. Determining factors of SOM chemistry remain poorly understood (von Lützow *et al.* 2006). This knowledge however is vital in understanding SOM stability under different soil conditions and global C sequestration. This work aims to establish a reconnaissance study in relating environmental factors to differences in NaOH-extractable SOM composition within a similar climatic context, i.e. maritime temperate forests in Belgium.

Methods
Nineteen forest sites were considered dominated by common European tree species, i.e. Scots pine (Pinus sylvestris L.), European beech (Fagus sylvatica L.), Pedunculate oak (Quercus robur L.) and hybrid poplar (Populus spp.). Two young pine forests on historical heathland and a recently forested heathland were also included. Samples were taken over the entire depth of the A-horizon and were given a code reflecting the dominant tree species of the sampling site (i.e. Pi, Fa, Qu or Po and FH for Forested Heathland), the soil-texture class (C for sandy loam and coarser or F for silt loam and finer) and the soil-moisture-regime class (depth of the highest ground water level being either deeper than 50 cm (D) or shallower (W)). Site variables included vegetation and standing biomass management, litter layer characteristics, total soil C and basic soil properties (Table 1). The hot water carbon (HWC) fraction and soil CO_2 respiration were evaluated as an indication for microbial contribution to the SOM. SOM was extracted by NaOH (0.1 M), yielding between 41 and 92% of the total C_{org}. The extract was acidified, dialyzed and freeze dried (Kaal *et al.* 2008). Freeze-dried samples were pyrolysed using a Curie-point pyrolyser GC-MS. Spectra were semi-quantified according to Buurman *et al.* (2009) and analysed by factor analysis. Spearman ρ correlation coefficients and ANOVA F-values were calculated between the factor scores and the environmental variables.

Results
Pyrolysis compounds included a range of alkenes (n:1) and alkanes (n); pristene (Pr); fatty acids (Fn); methylketones (Kn); an alcohol (Al); a terpene (T); aromatic compounds (A) containing benzene and indene related structures, toluene and styrene; four polyaromatic compounds (Pa); (poly)saccharide-derived

pyrolysis products (Ps) including furans, furaldehydes and monomeric sugars; lignin compounds derived from plant lignins of the guaiacol (G) and the syringol (S) types; nine phenol products (Ph) with various substituents; and twelve nitrogen-containing compounds (N, Figure 1). The first two factors explain 37.7% and17.6% of the observed variation. Factor loadings of the variables (i.e. the pyrolysis compounds) and scores of the cases (i.e. the samples) are shown in Figure 1. F1 is significantly correlated with tree species, litter layer characteristics, soil properties and HWC (Table 1). Pine stands on dry, sandy soils with considerable litter accumulation in the litter layer and mor-type humus are correlated with negative values on F1. These stands have low soil pH, low soil N content and low HWC content. Broadleaved stands with mull-humus types on rich soils with high microbial contribution (HWC) are positively correlated with F1. F2 is negatively correlated with the mass of the litter layer alone.

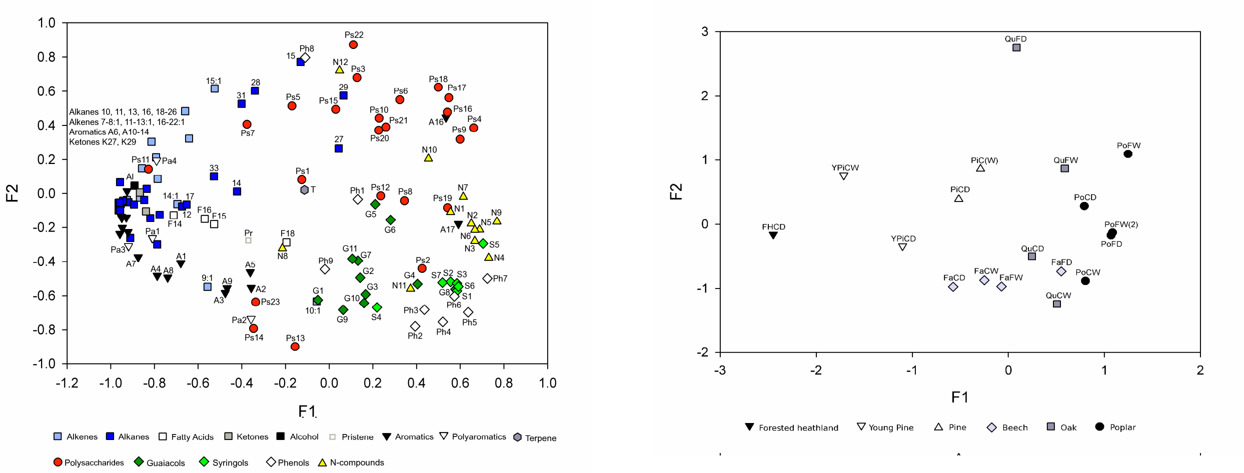

Figure 1. Factor analysis: factor loadings of the pyrolysis compounds (left) and factor scores of the samples (right) on the first two ordination axes. F1 opposes aromatics and short and mid-chain aliphatics (relatively recalcitrant) to lignin (especially syringols) and N-compounds. A gradient in dominant tree species can be observed along F1.

Discussion

Interpretation of pyrolysis-compounds

Short and mid-chain aliphatic compounds in pyrograms of soils mainly originate from aliphatic biopolyesters, derived from plant lipid precursors or microbial lipids. Aromatic pyrolysis products originate from SOM compounds derived from proteins (toluene), tannins and other (poly)-phenols including black carbon. As for the short and mid-chain aliphatics, aromatics are considered relatively recalcitrant to (further) microbial decay. Polysaccharide-derived pyrolysis-products relate to SOM molecules with both vegetal and microbial precursors. Ps9, Ps11 and Ps15-22 (and particularily the levosugars, Figure 1) are commonly related to biopolymers with cellulose-type precursors, referring to relatively weakly-decomposed, plant-derived SOM. Smaller polysaccharide pyrolysis products are mostly associated with microbial material (Ps1, Ps2, Ps4-6). Syringols and guaiacols are lignin-derived compounds. SOM found under coniferous vegetation typically shows a clear dominance of lignin compounds related to guaiacol, while broadleaved forests have SOM with both guaiacol and syringol compounds. Phenols in pyrolysis can have a variety of origins including lignins, carbohydrates, proteins or polyphenols. N-containing compounds in SOM may originate from vegetal or microbial precursors, or may be formed by chemical interactions. Abundance of N-compounds in SOM in non-fertilized soils is linked to high microbial influence (Vancampenhout *et al.* 2009 and references therein).

Interpretation of the factor analysis

Samples with strongly negative scores on the first factor F1 contain (i) a relative accumulation of aromatics and short and mid-chain aliphatics, which are fairly recalcitrant and indicative of degraded plant material; (ii) a relative absence of lignin (especially syringols) and (iii) a relative absence of N compounds. Strongly positive loadings on this axis on the other hand denote (i) the abundance of N-compounds, most likely linked to high microbial influence, and (ii) abundance of lignins and most of the polysaccharide compounds. Strongly negative loadings on F2 in combination with negative loadings on F1 indicate a relative abundance of possible markers of charring (benzofurans, benzonitrille, polyaromatics), while the lower right quadrant of the F1-F2 space represents a high abundance of lignin fragments, partly in combination with N-compounds.

Table 1. Spearman ρ correlation coefficients (r) and ANOVA F-values (F) relating site variables to the results of the factor analysis in Figure 1. Correlations are significant at 0.01(**) or 0.05 (*) level.

	Factor 1		Factor 2	
	F	r	F	r
Forest management				
Dominant tree species	16.56**		1.67	
Basal area		-0.08		-0.23
Stem number		-0.34		0.24
Cover herb layer		0.25		0.15
Forest age class	2.50		0.20	
Litter layer				
Humus index[A]		-0.69**		-0.08
Dry mass of litter layer		-0.69**		-0.50*
Soil properties				
Moisture class		0.55*		-0.13
Clay percentage		0.65**		0.02
Silt percentage		0.69**		0.00
Sand percentage		-0.73**		-0.04
pH (H_2O)		0.59*		0.44
N (%)		0.67**		0.04
N (Mg/ha)		0.55*		-0.02
Soil carbon				
C (%)		0.47		-0.07
C (Mg/ha)		0.36		-0.08
C/N ratio		-0.41		-0.35
Microbial activity				
CO_2 respiration		0.35		0.15
Hot Water Carbon[B]		0.77**		0.24

[A]Ponge and Chevalier (2006), [B]Ghani *et al.* 2003

The top centre of the F1-F2 space in Figure 4.3 represents compounds both indicative for relatively fresh (Ph8, alkanes 28-31 and possibly Ps22 and N12) and microbial (Ps3, alkane 15 and possibly Ps22 and N12) material, suggesting an admixture of both. Factor scores in Figure 1 emphasize a strong effect of dominant tree species on extractable-SOM chemistry (F1). Former heathland stands are still clearly distinguishable. The second factor F2 stresses the deviating composition of sample QuFD compared to samples taken under oak on light textured soils and under beech. This site has a complex site history, which could explain its unusual composition.

Influence of environmental factors

Despite the high inter-correlation between the environmental factors, the influence of dominant tree species on F1 is striking (Figure 1). Moreover, species are arranged along F1 according to their litter quality (Cornelissen 1996), indicating that input quality is an important determinant of the extractable-SOM composition in maritime temperate forests. An important accumulation of degraded, fairly recalcitrant mid-chain alkenes/alkanes and aromatics is observed in the extractable SOM under pine and former heathland forests. This accumulation coincides with a strong degradation of lignin- and cellulose-derived compounds (Figure 1) and associated to ecosystems with poor litter quality, moder type humus with thick and heavy litter layers, having low soil pH, low soil N content and low HWC content (table 1). This accumulation of recalcitrants (aromatics and short and mid-chain aliphatics) appears a common feature in soils where not all conditions for efficient decay are met (due to substrate limitations, occlusion, acidity, toxic ions, complexation, sorption, low fertility or oxygen deprivation; e.g. Buurman and Roscoe 2009; Ferreira *et al.* 2009). Soils under forested heathland and pine moreover have very low relative amounts of N-compounds (Figure 1). Oppositely, no accumulation of recalcitrants is present in the extractable SOM under poplar, which coincides with high abundance of N compounds, polysaccharides and syringols, generally linked to broadleaved forests with high microbial influence.

This is further evidenced by the high positive correlation of F1 to microbial proxies (HWC) and to ecosystems with high litter quality, mull-type humus and thin litter layers (table 1). Remarkably, the soil's nutrient status shows stronger correlation to the decomposition of recalcitrants than oxygen deprivation. No general relation of extractable-SOM chemistry with time under forest was found, yet forested heathland and the younger pine forests (forested since 1940 or longer) clearly have more negative scores on F1, as compared to PiC(W) and PiCD (permanently forested at least since 1775 and 1850, respectively). This indicates that the former heathland vegetation still has a detectable influence on the extractable-SOM chemistry under pine forests established for 60 years or more. Under poplar, beech and oak however, the period under forest does not appear to have much effect on extractable-SOM chemistry.

Conclusion

The results of this study indicate that vegetation is a major factor determining the extractable-SOM composition in maritime temperate forests. Aliphatics and aromatics accumulate in the extractable SOM of ecosystems with poor soils and low litter quality. Their decomposition seems hampered in such conditions, whereas all carbon sources seem effectively used if conditions for decomposition are favorable (i.e. eutrophic ecosystems with high litter quality, which show no accumulation of recalcitrants yet high amounts of N-compounds). Correlations between extractable-SOM chemistry, litter layer properties and Hot-Water-Carbon content further support this hypothesis. The long lasting influence of former heathland on the accumulation of recalcitrants in the extractable-SOM composition of pine forests indicates that chemical recalcitrance is relevant in certain ecosystems for several decades.

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References

Buurman P, Nierop KGJ, Kaal J, Senesi N (2009) Analytical pyrolysis and thermally assisted hydrolysis and methylation of EUROSOIL humic acid samples - A key to their source. *Geoderma* **150,** 10-22.

Buurman P, Roscoe R (2009) Different decomposition paths of free light and occluded light SOM fractions in soils of cerrado, tilled and untilled fields, Minas Gerais, Brazil - a pyrolysis-GC/MS study. (In Preparation).

Cornelissen JHC (1996) An experimental comparison of leaf decomposition rates in a wide range of temperate plant species . *Journal of Ecology* **84,** 573-582.

Ferreira FP, Vidal-Torrado P, Buurman P, Macias F, Otero Perez XL, Boluda R (2008) Pyrolysis-gas chromatography/mass spectrometry of soil organic matter from a Brazilian mangrove and Spanish salt marches. (In Preparation).

Ghani A, Dexter M, Perrott KW (2003) Hot-water extractable carbon in soils: a sensitive measurement for determining impacts of fertilisation, grazing and cultivation. *Soil Biology and Biochemistry* **35,** 1231-1243.

Kaal J, Martinez-Cortizas A, Nierop KGJ, Buurman P (2008) A detailed pyrolysis-GC/MS analysis of a black carbon-rich acidic colluvial soil (Atlantic ranker) from NW Spain. *Applied Geochemistry* **23,** 2395-2405.

Ponge JF, Chevalier R (2006) Humus Index as an indicator of forest stand and soil properties. *Forest Ecology and Management* **233,** 165-175.

Vancampenhout K, Wouters K, De Vos B, Buurman P, Swennen R, Deckers J (2009) Differences in chemical composition of soil organic matter in natural ecosystems from different climatic regions - A pyrolysis-GC/MS study. *Soil Biology and Biochemistry* **41**, 568–579

von Lützow M, Kögel-Knabner I, Ekschmitt K, Matzner E, Guggenberger G, Marschner B, Flessa H (2006) Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions - a review. *European Journal of Soil Science* **57,** 426-445.

Development of soil quality indices for natural forest habitats of lowlands and uplands in Poland and its application in silviculture: project description.

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Abstract
The project involves a soil study for natural forest plant communities as a model for sustainable development of forest resources in Poland. The objective of this project is to describe the features of soils typical for specific forests types, to prepare them in a classical format and in the numerical soil quality index (SQI) and to implement this knowledge in forestry practice. Application of this index in forest site cartography is an innovation and constitutes significant progress in the research on natural soil/plants relations, which facilitates planning the plant composition for a renewed forest. The scope of work covers defining around 200 research plots within Poland's lowlands and highlands. The soil biogeochemical analyses will be held along with plant composition description and work on tree taxonomy. The research also covers the impact of individual species on soil properties, which allows description of its variability in time and space as well as its effects for SQI. The research covered by this project provides for a better use and management of forest soil resources. Sustainable forest growth as the main purpose of its management, which means integrating the production of timber, energy, clean water, carbon storage and biodiversity with the tourist and curative values of forests, is of high importance to the society. It is directed at improving the biological diversity in silviculture, as well as in farmlands designed for afforestation.

Key Words:
Pine, oak, spruce, beech, hornbeam.

Introduction
Throughout the last couple of decades, there has been a growing concern about the condition of soil quality as a measure of its capacity for performing such functions as producing plant biomass, maintaining animal health, recycling of nutrients, storing carbon, separating and distributing rainfall, buffering acidity (from anthropogenic sources), degradation and remediation of organic waste and regulating energy transformations.(Schoenholtz *et al*. 2000). Soil quality has been defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen *et al*. 1997). Monitoring both agriculture and forest management requires looking at the overall quality of the soil to foresee possible changes in productivity. Productivity is a product of different factors, and in silviculture various measures of productivity have been used over the years. A site index (e.g. canopy height of a tree of a given age) is the most commonly used measure of productivity, and is influenced by factors such as climate, slope and other landscape features (geologic and topographic features), combined with soil quality. However, if the impact on productivity of various management practices in silviculture needs to be evaluated, it is more convenient to use a soil quality index (SQI). Management practices may influence the soil's chemical, physical and biological attributes, but usually they do not affect other aspects of site quality, such as the geologic and topographic features. A soil quality index is based on the assumption that there is a direct relationship between the below-ground processes (including root growth) and the aboveground productivity, and hence a particular soil attribute that restricts root growth may result in decreased aboveground productivity (Burger and Kelting 1999)

In the case of Polish forests, this standard environment management practice starts with mapping of a habitat. This work is performed for small forest areas. A proper soil survey makes the basis for a proper expertise regarding habitat and forest species composition. The classic approach to soils within habitat mapping is based on soil types, sub-types and kinds, which until now did not produce satisfying results, in particular regarding the relationship with a forest tree species composition. Soil types and subtypes are relatively large units and it is difficult to establish their clear relation to forest tree species composition. The most valuable knowledge of soil, in particular with reference to the relationship between soil and flora, is related to its properties. Laboratories provide a huge amount of data that is difficult to interpret. In the recent years there have been attempts to develop soil numerical indices that would be simple indices covering numerous properties (Andrews 2003, Huber 2005, Schoenholtz *et al*. 2000).

The first objective of this project is to specify the soil characteristics typical of forests of various composition, presenting them in the classical format and as a relatively robust, numerical quality index, and then implementing this knowledge in forestry practice. The second objective is to recognize the potential changes in soil quality indices caused by changes in forest species composition.

Methods

One part of this project is focused on finding the relationship between soil quality indices and natural forest plant communities. The work includes plant composition description, tree measurements (height, breast diameter, increment, age), soil profile characteristic and sampling. The laboratory work includes an analysis of 1,200 samples taken to cover the texture, bulk density, total nitrogen (N) and organic carbon (C) contents, soil pH in H_2O and in 1M KCl, exchangeable acidity (TE), total acidity (TA) and exchangeable Ca^{2+}, K^+, Mg^{2+} and Na^+.

The other part of the project deals with the influence of forest species on the values of soil quality indices. Research is carried out on 12 plots. For this purpose, the following pairs of plots were selected: Pine/Oak (3 pairs), Pine/Beech, Pine/Hornbeam, Pine/Spruce. The paired plots are relatively close to each other and stand on the same soil type. The plots are 20m x 20m in size. During field work, the plots were mapped (ground surface variability, location of stems and tree crown range). Soil sampling is performed on a 1x1m grid (441 per plot), samples are taken from the top 10cm, mineral-only layer of soil. These samples are being analyzed for pH in 0,01 M $CaCl_2$ solution, and for moisture content. Additionally, 16 samples from each plot are taken on a 4x4 m grid and analyzed for: pH, base cations content, total and exchangeable acidity, aluminium extracted in 1 M KCI and 0,5 M $CuCl_2$, total C and N. On some of tested plots a set of lysimeters are installed for soil solutions sampling at the depth of about 10 and 20cm. Soil solution analysis includes the following factors: pH, H^+, Ca^{2+}, Mg^{2+}, K^+, Na^+, Al (total and $Al^{(3-n)}$), $Fe^{2+,3+}$, Cl^-, SO_4^{2-}, NH_4^+, NO_3^- contents.

Preliminary results

On the basis of previous research (Brożek *et al.* 2006) and statistical analysis of the data (Brożek 2007), four groups of soil properties were selected as indicators for calculating the soil quality index. The selected indicators, calculated for 1x1x1.5m soil volume, comprised:

- the content of the <20 µm (fine) fraction of the (FF sum),
- the content of base cations (BC sum),
- soil acidity per weight unit of the <20 µm fraction (TA/FF),
- N^2 to C ratio in the top soil (N^2/C) – this parameter calculated only for the A horizons.

The next step was categorization. Each of the four indicators is subdivided into 10 classes (1 to 10) (Table 1). The highest value (10) is best for the soil quality.

Table 1. Categories of the chosen soil indicators.

class	FF sum (kg)	BC sum (kg)	TA/FF ($cmol_+$/kg)	N^2/C (%)
	range	range	range	range
1	<20	<2.3	>1.50	<0.002
2	20-45	2.4-3.6	1.50-1.11	0.0021-0.003
3	46-55	3.7-5.0	1.10-1.01	0.0031-0.0036
4	56-75	5.1-7.5	1.00-0.81	0.0037-0.0050
5	76-100	7.6-9.5	0.80-0.61	0.0051-0.0065
6	101-120	9.6-13.0	0.60-0.51	0.0066-0.0080
7	121-250	13.1-25.0	0.50-0.36	0.0081-0.0100
8	251-500	25.1-50.0	0.35-0.21	0.0101-0.0150
9	501-950	50.1-350	0.20-0.10	0.01501-0.020
10	>950	>350	<0.10	>0.02

First of all, this project is designed to choose the soil indicators that distingushing natural plant communities and to continiue the work on the classess and SQI formula.

At present, the investigations are being carried out, all fieldwork have been performed. Sampling on trial plots are also finished, and the results of the laboratory analysis are soon expected. In order to obtain the preliminary information on the impact of forest species composition on the investigated soil quality indices, we used data from the soils of homogeneous spruce forest and mixed forest predominated by European beech. Some of soil properties (e.g. texture) are dependent primarily on the parent material and considered stable, whereas others could be affected by forest type. However, both these indices and the soil quality index were developed for lowlands, and we tested their applicability to mountain forest soils.
Not surprisingly, the content of the <20 μm fraction proved to be the most stable parameter, while the content of base cations proved to be the most affected (Table 2). The magnitude of shift in the values of the soil quality index between the spruce and mixed forest was also related to the type of parent material and was most pronounced in the richest soils.

Table 2. Parameters of the soil quality index calculated for soils under spruce stands and mixed stands (average values).

Type of forest	number of profiles	Sum in profile up to 150 cm			In the A horizon
		FF sum	BC sum	TA/FF	N^2C
Spruce	36	894	28	0.362	0.018
Mixed	18	910	45	0.328	0.021
Relative change [%]		+2	+38	-10	+17

Conclusions for the project

The planned final outcome of this project is determination of the soil quality indices which will be used in habitats mapping and in planning the species composition within forest management. The developed SQI is intended to be robust and resistant to the possible influence of forest species composition. Additionally, it should be simple enough to be used in forest service as a tool for forest management promoting biodiversity and afforestation of farmlands.

Our conclusions are that the extant soil quality index is relatively stable and practically uninfluenced by forest vegetation. The only parameter strongly affected was that based on the sum of base cations. Additionally, the tests performed demonstrate that the index can also be successfully applied to mountain soils. Another important question to answer is the small-scale spatial variability of soil quality parameters. How strongly can a singular tree affect it? How many sampling points are required to cover the local soil properties variability with only an acceptable statistical error?

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References

Andrews SS, Karlen DL, Mitchell JP (2002) A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agriculture, Ecosystems and Environment* **90**, 25-45.

Brożek S, Zwydak M, Lasota J (2006). Soil properties applied in forest site classification of lowlands and uplands in Poland. *Mitt Österr Bodenkundl Ges*, *Heft* **73**, 87-95.

Brożek S (2007) Soil quality numerical valorisation – a tool in forest site diagnosis (in Polish with English summary). *Sylwan*, **CLI**, 35-42.

Burger JA, Kelting DL (1999) Using soil quality indicators to assess forest stand management. *Forest Ecology and Management* **122**, 155-166.

Huber S (2005) The Austrian soil indicator set and its development. *Mitt Österr Bodenkundl Ges, Heft* **73**, 13-19.

Karlen DL, Mausbach JJ, Doran JW, Cline RG, Harris RF, Schumann GE (1997) Soil quality: a concept, definition, and framework for evaluation. *Soil Science Society of America Journal*, **61**, 4-10.

Schoenholtz SH, Van Miegroet H, Burger JA (2000) A review of chemical and physical as indicators of forest soil quality: challenges and opportunities. *Forest Ecology and Management* **138**, 335-356.

Effects of manganese concentration on beech leaf litter decomposition: results from field and laboratory experiments

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Abstract
Lignin degradation is considered to be the rate limiting step of litter decomposition, a vital process in forest biogeochemical cycles. Mn concentration may play a key role in lignin degradation as it is essential for the activity of manganese peroxydase (MnP), a central enzyme of the lignin degrading system. We investigated the impact of Mn on litter decomposition by incubating for one year beech leaf litter of different Mn concentrations (40, 45, 60 and 120 mmol/kg$_{DM}$) in laboratory and in the field (litterbags). We determined carbon and nitrogen releases as well as the variation of leaf litter composition over time. With Mn concentration, leaf litters exhibited an increase in total CO_2 release, a decrease in total DOC release, along with a decrease in $NO_3^-/(NH_4^+ + NO_3^-)$ ratio and in carbon content and C/N ratio. In the light of our results, we hypothesize that higher Mn concentration (i) could improve biological activity and/or (ii) could promote ligninolysis. To support and confirm these hypotheses, we completed our study by considering the evolution of the content and the oxidation state of leaf litter lignin.

Key Words
Forest organic matter, lignin degradation, carbon and nitrogen releases, laboratory incubation, litterbags.

Introduction
Litter decomposition is of crucial importance for sustainable production in forest ecosystems, because it is responsible for carbon and nutrient cycling. Due to its complex and heterogeneous structure, lignin degradation is slow and exerts a major control on organic residues decomposition. Therefore, lignin concentration is generally considered to be an indicator of substrate quality (Melillo and Aber 1982).
Among the factors affecting the degradation of lignin, Mn concentration may play a key role since Mn is essential for the activity of manganese peroxydase (MnP), the most wide-spread enzyme of the lignin degrading system secreted by the white-rot fungi (Hofrichter 2002). Kerem and Hadar (1995) demonstrated a positive effect of Mn on lignin degradation during the solid-state fermentation of a cotton fibre. Correlation between Mn concentration and litter carbon mineralization was also observed (Berg *et al.* 2007); nevertheless the role of Mn on litter decomposition has not yet been experimentally tested.
This study aims to assess the impact of Mn concentration in beech (*Fagus sylvatica* L.) leaf litter on carbon and nitrogen release (laboratory incubation) and on leaf litter chemical composition (field experiment) during the decomposition process.

Methods
Manganese concentrations in beech leaf litter
Leaf litters with identical composition, except Mn concentration, were obtained by dipping branches in Mn solutions (0 to 2.5 mM) for 10 days (Table 1). Manganese was transported through the transpiration stream and accumulated in leaves. Branches were sampled from beech trees from Bois de Lauzelle (Table 2) at the beginning of spring. We also examined beech leaf litter from the Transinne site (Table 2). Beech leaf litters from Bois de Lauzelle (Mn0 treatment) and from Transinne were identically concentrated in Mn but Transinne leaf litter exhibited a greater decomposition capacity (data not shown).

Laboratory experiment
Beech leaf litters were incubated in triplicate in columns hermetically closed for 350 days at 20°C. Carbon and nitrogen releases were determined during the incubation period. CO_2 was measured by back titration of a NaOH solution. Leachates were obtained by water extraction from beech leaf litter subsamples. On these leachates, dissolved organic carbon (DOC) was quantified using a carbon analyzer (Dohrman DC-180), absorbance (280 nm) was measured using a UV/VIS spectrometer UNICAM8625 and inorganic nitrogen ($NH_4^+$and NO_3^-) determined using a HPLC (Dionex LC20 with IONPAC AS 11 column).

Table 1. Mn concentrations in beech leaf litters subjected to different treatments [mmol/kg$_{DM}$].

		--------------- Bois de Lauzelle ---------------			
Treatment abbreviation	Transinne	Mn0	Mn1	Mn2	Mn3
Mn concentration in dipping solution [mM]	0	0	0.5	1	2.5
Leaf Mn concentration [mmol/kg$_{DM}$]	40	40	45	60	120

Field experiment (litterbags)

For each type of litter, the samples of about 2.5 g each were enclosed in separate litterbags (18 x 18 cm) made of polyester net with an upper mesh size of 2.4 mm and a lower mesh size of 0.5 mm. In November 2008, in the Forêt de Soignes (Table 2), litterbags were placed below the L layer in a randomized design. The procedure was replicated 4 times by leaving the litterbags in 3 different location to avoid pseudoreplication; the bags were then collected 5 (150 days, t_1), 10 (300 days, t_2) and 15 months later. Plant remains such as mosses and roots were removed. Then, the mass loss was determined by drying the sample at a constant temperature of 60°C. We quantified carbon and nitrogen contents using a NC-soil analyzer.

Table 2. Sites used in this study, their geographic location (Belgium), climate, soil and forest floor type.

	Bois de Lauzelle	Transinne	Forêt de Soignes
Location	Louvain-la-Neuve, 49°59’03”N, 5°11’31”E	Belgian Ardenne, 50°48’24”N, 4°28’04”E	Brussels, 50°40’44”N, 4°36’15”E
Mean annual temperature	9.4 °C	8.7 °C	9.4°C
Mean annual precipitation	816 mm	1035 mm	835 mm
Soil	Cambisol	Dystric cambisol	Podzol
Forest floor	Mor	Moder	Mor

Statistics

The differences between means were compared with Fisher’s least significant difference (LSD) test. Using the laboratory results, the test was carried out by one-way variance analysis (Anova1), treatment being the factor. Then, using the field experiment results, the LSD-test was performed by two-ways variance analysis (Anova2), allowing us to take into account the variability introduced by the location factor and by its interaction with the treatment factor. All the statistical analyses were performed with the SAS software (SAS Institute 1999) with a significance level of 0.05.

Results

From laboratory experiment

At the end of the incubation period, the Mn3 leaf litter exhibited a significant a larger total CO_2 release than Mn0 and Transinne leaf litters (p-value of 0.0148). Except for Transinne leaf litter, leaf litter Mn concentration was higher while the total DOC release (p-value of 0.0001) was lower (Figure 1). Nevertheless, DOC in water extracts exhibited no significant difference of molar absorptivity (absorbance at 280 nm/DOC concentration) between the treatments.

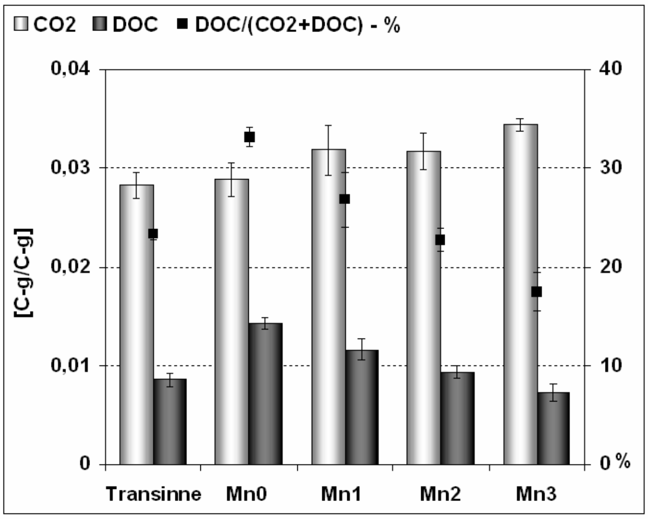

Figure 1. Cumulative release of carbon (CO_2 and DOC) over the incubation period (left Y-axis) and DOC/(CO_2 + DOC) ratio (right Y-axis).

Ammonium release was highest in Mn3 leaf litter water extract and the lowest in Transinne leaf litter extract (p-value of 0.0006). Nitrate releases were twice as low in Mn2 and Mn3 leaf litter extracts than in the water extracts of the other treatments (p-value of 0.0154). The nitrification degree ($NO_3^-/NH_4^+ + NO_3^-$) was significantly greater for nitrogen release from the Transinne leaf litter. For the other treatments, nitrification degree decreased with Mn concentration in leaf litter (Table 3).

Table 3. Cumulative release of nitrogen (NH_4^+ and NO_3^-) over the incubation period and nitrification degree ($NO_3^-/NH_4^+ + NO_3^-$). Means and their standard deviations are presented (n=3). Means with different associated letters are statistically different (α = 0.05).

Treatment	Transinne	Mn0	Mn1	Mn2	Mn3
NH_4^+ [N-mg/N-g]	0.012 ± 0.007 c	0.037 ± 0.001 b	0.030 ± 0.001 bc	0.046 ± 0.005 b	0.078 ± 0.019 a
NO_3^- [N-mg/N-g]	0.014 ± 0.004 a	0.012 ± 0.004 ab	0.012 ± 0.001 ab	0.007 ± 0.001 bc	0.005 ± 0.001 c
Nitrification degree - %	56.4 ± 7.4 a	24.7 ± 5.7 bc	30.7 ± 11.4 b	13.5 ± 2.7 cd	6.5 ± 1.6 d

From field experiment

After 150 days in the field, we observed no significant difference in mass loss between leaf litters subjected to different treatments in litterbags the mass loss ranged between 10 and 20%. After 300 days, Transinne leaf litter exhibited a significant larger mass loss (30%) than the other leaf litters (20 – 25%) (p-value of 0.0383). After 300 days in the field, the leaf litter with the largest Mn concentration (Mn3) exhibited a decrease of carbon content significantly larger than the other leaf litters (p-value of 0.05) (Figure 2a). The leaf litter with the lowest Mn concentration (Mn0) exhibited the lowest increase of nitrogen content, already after 150 days (p-value of 0.0020 (t_1) and 0.0037 (t_2)) (Figure 2b). Over time, the decrease of C/N ratio in leaf litter material was lowest for Mn0 leaf litter and highest for Mn3 leaf litter (p-value of 0.0001 (t_1) and 0.0002 (t_2)) (Figure 2c).

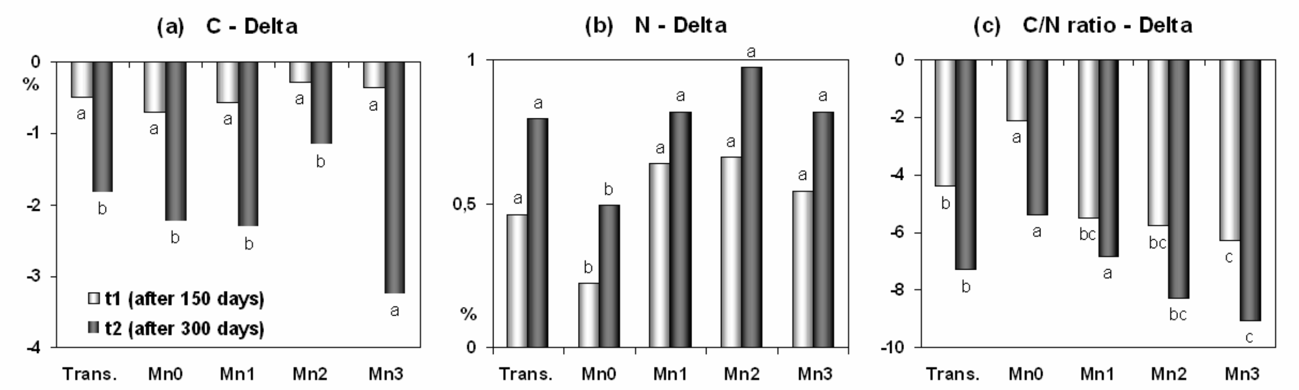

Figure 2. Difference in C-, N-content and C/N ratio between leaf litters sampled after 150 (t_1) or 300 days (t_2) and corresponding initial leaf litters (t_0).

Discussion

Carbon release

Our results suggest that Mn concentration affects carbon release. Total carbon (CO_2 + DOC) released by the leaf litters treated stayed constant. However, the form of released carbon evolved in favor of the mineralized form (CO_2) with Mn concentration in leaf litters. The DOC composition is complex and heterogeneous. The main sources of DOC are C-labile and ligninolysis products (hydrophobic components) (Guggenberger 1994). Our study suggests there was no variation in the composition of DOC released by the leaf litters treated, just as there was no variation in molar absorptivity. In fact, molar absorptivity estimates DOC aromaticity and indicates the quantity of hydrophobic components (Simonsson *et al*. 2005). In the field, leaf litter with the most Mn concentrated (Mn3) had the largest carbon loss. Field conditions (more moisture, involvement of micro- and macrofauna because of the litterbags design) could enhance biological processes.

We could hypothesize that Mn concentration (i) improves biological activity and/or (ii) promotes ligninolysis. In the first hypothesis, microorganisms could consume more C-labile (decrease of DOC release) and could produce more respiration (increase of CO_2 release). In the second hypothesis, lignin degradation could be more complete. Thus, microorganisms could have easier access to ligninolysis products.

Nitrogen release
Our results also suggest that the level of Mn concentration affects nitrogen release. According to the first hypothesis, the decrease in NO_3^- release could be explained by a larger consumption of microorganisms. In the second hypothesis, the decrease in $NO_3^-/NH_4^+ + NO_3^-$ ratio in leaf litters with large Mn concentration could be explained by depression in the nitrification process. Dissolved polyphenolic compounds produced by ligninolysis could inhibit nitrification (allelopathy) (Killham 1990).

Conclusions and perspectives
By reducing the C/N ratio, a classic indicator of litter decomposition (Figure 2c), Mn concentration impacts litter decomposition by improving biological activity or/and by promoting ligninolysis. To support and confirm these hypotheses, we will consider the evolution of the content and the oxidation state of leaf litter lignin in our laboratory and field samples. Moreover, we await results from the last collection of litterbags in order to study the temporal evolution of leaf litter composition.

References

Berg B, Steffen KT, McClaugherty C (2007) Litter decomposition rate is dependent on litter Mn concentration. *Biogeochemistry* **82**, 29-39.

Guggenberger G (1994) Acidification effects on dissolved organic matter mobility in spruce forest ecosystems. *Environmental international* **20**, 31-41.

Hofrichter M (2002) Review: lignin conversion by manganese peroxydase (MnP). *Enzyme and Microbial technology* **30**, 545-566.

Kerem Z, Hadar Y (1995) Effect of Mn on preferential degradation of Lignin by *Pleurotus ostreatus* during solid-state fermentation. *Applied and Environmental Microbiology* **61**, 3057-3062.

Killham K (1990) Nitrification in coniferous forest soils. *Plant and soil* **128**, 31-44.

Melillo JM, Aber JF (1982) Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* **63**, 621-626.

SAS Institute (1999) ‘SAS/STAT User’s guide, version 8 for window’. (SAS Institute, Inc.: Cary, North Caroline, USA).

Simonsson M, Kaiser K, Danielsson R, Andreux F, Ranger J (2005) Estimating nitrate, DOM and DOC fractions in forest floors leachates using ultraviolet absorbance spectra and multivariate analysis. *Geoderma* **124**, 157-168.

Effects of balanced fertilization on bamboo's quality

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Abstract
Moso bamboo forest is an important forest resource in southern China. The results of balanced fertilizing in Jiangxi and Hubei bamboo forests showed that: balanced fertilization can increase the bamboo diameter, improve the quality of bamboo shoots and increase economic efficiency and yields. The influence on mechanical properties of bamboo is not obvious. Balanced fertilization can also reduce fertilizer waste and pollution. Balanced fertilization of bamboo forest and good management guarantees of improved productivity and quality, increased economic and ecological benefits in South China.

Key Words
Moso bamboo, balance fertilization, quality.

Introduction
Moso bamboo is the most widely distributed species occupying the largest area of cultivation, the largest reserves, has the highest economic value wood and bamboo shoots in China's bamboo forests. It occupies a very important position in forestry production in China. Bamboo with its fast growth, early useful wood, the wide use, the wide receipts, and other major characteristics are an important forest resource of the South in China. The recent 10 years, the area of bamboo increased at a rate of 51,000 hm^2 each year in China. Among them, *Moso* bamboo increased 76,000 hm^2 within the recent 5 years. Bamboo plays an important role in human life and production. It receives wide attention in world forest production. It not only provides industrial and agricultural production and people's lives are affected by the bamboo through bamboo shoots and bamboo by-products of raw materials, but bamboo also affects water and soil and water conservation, regulation of climate, landscape environment and other effects. *Moso* bamboo will have an irreplaceable role to meet the country's "bamboo instead of wood" and "bamboo instead of plastic".

Methods
The main producing areas are in Fengxin, Jing'an, Chibi, and other cities and counties in Jiangxi Province, Hubei Province. South Bamboo main production types and site conditions, the same basic rotation of bamboo-bamboo with balanced fertilization of pilot sites are represented by Fengxin, Jing'an and Chibi in the humid subtropical monsoon climate. The mean annual temperature is 17.4 ℃ with a frost-free period of 280 d, a mean annual rainfall ranging from 1612.5 to 1955.7 mm, the sunshine hours 1802.5 h, the total radiation is 106 kcal/cm^2.
Fengxin, Jing'an District uses on completely randomized design group designed trial, Hubei Chibi a incompletely random group. Analyses include bamboo shoot nutritional quality (protein hydrolysis amino acid method, Kjeldahl, residual method, detergent, anthrone color, burning method, atomic absorption spectrophotometry, sodium tungstate colorimetric method, 2,4-Dinitrophenylhydrazine Colorimetry)

Results
Fertilization on the impact of bamboo DBH
Fertilization and reclamation measures improve the average diameter at breast high (DBH). In the data about the average DBH in Fertilization, 1-3 year new bamboo, the average annual increase is 2.46 percent. The average fertilized DBH, 3-5 year new bamboo, the average increase is 7.93 percent. With fertilizer increasing, average DBH between fertilization treatment and CK (reclamation tending) has significant differences. It indicates that it is very important of fertilizer inputs to the maintenance of average diameter.

Balanced fertilization on the impact the nutritional quality of bamboo shoots
The difference N, P, K ratio in six treatments for the six treatments. But compared to CK (reclamation), the nutritional content of bamboo shoots improves with respect to protein, sugar, fat, VC, fibre etc., which show

higher values than those in non-fertilized treatments. In particular, the sugar content increases 38.7 percent.

Balanced fertilization impacts on Moso bamboo wood properties
To test *Moso* bamboo wood properties after four years continuous fertilization wiyh different N and P rates in Hubei Chibi. In general, string bending strength was slightly lower than the control, radial bending strength, along the grain compressive strength and tensile strength of slightly higher than those in control.

Conclusion
The DBH increment relationship with fertilization treatment is larger than for CK (reclamation). The largest growth reached 11.2 percent in $N_2P_2K_2$, followed by $N_1P_1K_2$, relatively increment 10.3 percent. The next highest growth response is 9.9% in $N_2P_1K_2$ treatment, which is more than four-fold that for CK (reclamation). It is very important that fertilizer inputs improve the quality of bamboo.
Fertilization improve the protein, sugar, fat, VC, fibre and nutrient contents of bamboo shoots, in particular, the sugar content increased 38.7 percent. From the perspective of using bamboo shoots, the highest yield of bamboo shoots with $N_2P_1K_1$ reached 4363 kg/hm^2, an increase of 90.72 percent over Control. The other treatments in order of the relative production of bamboo shoots: $N_1P_1K_2$ (162.7%)> $N_2P_2K_2$ (160.6%)> $N_2P_1K_2$ (159.4%)> $N_1P_1K_1$ (135.5%)> N_1P_1 (126.0%)> CK (reclamation) (100%). Fertilizers N, P and K nutrients play a vital role in the growth of bamboo shoots. Fertilization has a certain impact on bamboo culm properties. Different fertilizer ratios have different impacts on bamboo mechanical properties. Their mutual relations are more complicated. At the same low-N, P level, more K fertilization can improve bamboo mechanical properties. Excessive fertilization may decrease timber. Based on the utilities of the *Moso* bamboo, we need to choose suitable fertilizer ratios to maximize economic efficiency.

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References
Bai XJ (2000) China's crop balanced fertilization technology strategic thinking in the beginning of the century. *Agricultural Technical and Economic*,
Chen H,Hong W, Lan B (1998) Study on Moso bamboo forest biomass and productivity of Northern Fujian Province. *Forestry Science* **34** (1), 60-64.
Chen JH, Li QY, Yang DC (1998) China's forest fertilization and nutrition diagnosis. *World Forestry Research*.**3**, 58-65.

Effects of ecological succession on chemical characteristics of humic and fulvic acids in a Japanese volcanic ash soil.

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Abstract
To obtain further details regarding effects of ecological succession on chemical characteristics of humic and fulvic acids in a Japanese volcanic ash soil, humus quantitative analysis, HPSEC, and liquid-state ^{13}C NMR analysis were performed with surface mineral soils (0–20 cm). Grassland at site 1 has been maintained by mowing, while the maintenance of sites 2 (pine forest) and 3 (broad-leaved forest) was discontinued approximately 30 and more than 100 years ago, respectively. The concentration of humic acids decreased from 60.4 to 47.4 C g/kg in only 30 years (site 1 vs. site 2), and then decreased from 47.4 to 30.2 C g/kg after 100 years (site 2 vs. site 3). Simultaneously, the concentration of fulvic acids decreased only slightly throughout the series (site 1 to site 3). Physicochemical properties appeared to be affected by succession only in humic acids. In particular, the proportion of aryl C moieties in the humic acid of site 2 decreased from 49.6 to 31.4%, a level similar to that of site 3. The findings of this study clearly demonstrate that humic acids, but not fulvic acids, significantly changed with decreasing aryl C content, over the first 30 years and then remained fairly constant.

Key Words
Secondary succession; Black soil; Stability of soil organic matter; Carbon sequestration.

Introduction
Japanese volcanic ash soils have very thick and dark-colored A horizons with large amounts of humic acids (Wada 1986) which are characterized by their highly aromatic structures and stabilities such as black carbon (Shindo and Honma 2001). Nevertheless, the disappearance of the melanic epipedon with a decreasing aromatic C and increasing alkyl C proportion of humic acids was observed in ecological succession over only 20−30 years in the grassland/forest ecotone of volcanic ash soil in Japan (Golchin *et al.* 1997). However, there is no clear information on how such quantitative changes in each carbon species affect chemical properties of humic substances. To obtain clearer information about this, we therefore aimed: (1) to quantify the time series variation of humic and fulvic acid, dominant portions of soil organic matter; (2) to determine the chemical properties of humic and fulvic acids quantitatively. We investigated the concentration of humic and fulvic acids extracted from volcanic ash soil at the same study site as that of Golchin *et al.* (1997). To obtain the quantitative variations in each carbon species and their effects on the chemical properties of humic and fulvic acids, we performed liquid-state ^{13}C nuclear magnetic resonance (^{13}C NMR) spectroscopy with the humus quantitative analysis. We also determined the relative molecular weight of each humic and fulvic acids by high-performance size exclusion chromatography (HPSEC).

Materials and Methods
Study area
The study area is situated in the campus of the Sugadaira Montane Research Center (SMRC) of Tsukuba University, Nagano Prefecture, Japan (36°30′N, 128°20′E), at 1320 m above sea level. The mean annual temperature is 6.5°C and the mean annual precipitation is 1190 mm. The initial soil is derived from volcanic ash, classified as Typic Melanudand (USDA Soil Taxonomy). The study sites were managed as grassland for several hundred years. At the site 1, regular mowing has been practiced to maintain the grassland (site area: 6 ha); however, at the site 2, mowing of the grasslands ceased approximately 30 years ago (site area: 8.5 ha), and at the site 3, grassland was invaded by forest at least more than 100 years ago (site area: 14 ha). The dominant vegetative cover was Japanese pampas grass, *Miscanthus sinensis*, at the site 1, *Pinus densiflora* with an understory of *Sasa* spp. at the site 2 and *Quercus crispula* with an understory of *Sasa* spp. at the site 3. Location and present site sketch of the study area are shown in Figure 1.

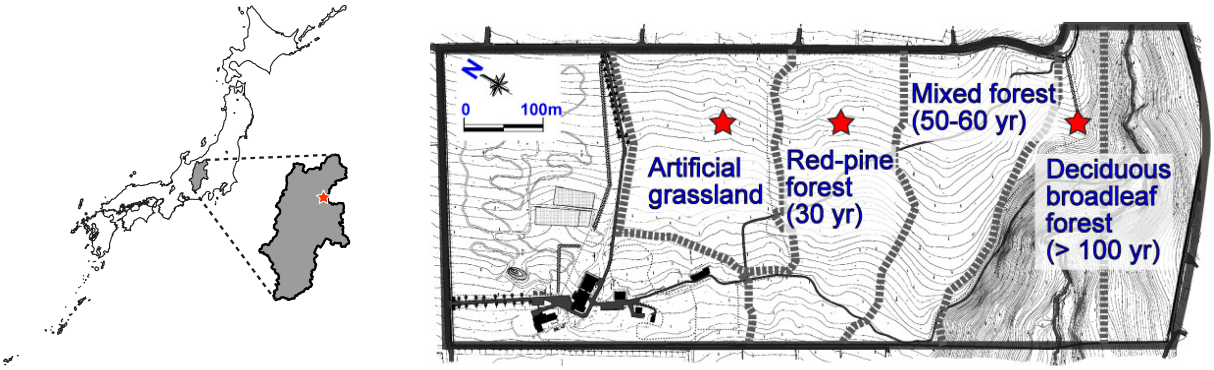

Figure 1. Location and site sketch of the study area.

Preparation of humic and fulvic acids
Soil samples were collected from 0−20 cm surface mineral soil. The amounts of humic and fulvic acids were determined according to the method described by Ikeya and Watanabe (2003). For chemical characteristics, humic and fulvic acids were isolated using standard methods of the international humic substances society (IHSS) with some modifications (Swift 1996; Fujitake and Kawahigashi 1999).

Analysis of humic and fulvic acids
The relative molecular weight of humic and fulvic acids was estimated according to the method of Asakawa *et al*. (2008). Liquid-state ^{13}C NMR spectra were obtained using a Bruker Avance 500 spectrometer with 5 mm diameter sample tubes. Approximately 30−50 mg of the sample was dissolved in 0.4 mL of 0.5 mol/L NaOD in D_2O. Chemical shifts were referenced to sodium 3-trimethylsilylpropionate-2,2,3,3 D_4. To obtain quantitative conditions for the integration of the ^{13}C NMR spectra, ^{13}C signals were proton-decoupled using the inverse-gated decoupling technique as follows: spectrometer frequency, 125.76 MHz; pulse width, 45°; acquisition time, 0.839 s. A total repetition time of 2.5 s was used to permit complete relation of all the spins. To improve the signal-to-noise ratio, a line broadening of 50 Hz was used. Scans numbering 10,000 to 20,000 were accumulated. Resonance areas were calculated using electronic integration. To obtain quantitative information, the spectra were divided into the following six regions (Fujitake and Kawahigashi 1999): alkyl C (5−50 ppm), O-alkyl C (50−110 ppm), aryl C (110−145 ppm), O-aryl C (145−165 ppm), carboxylic C (165−190 pp) and carbonyl C (190−220 ppm). Aromaticity proposed by Hatcher *et al*. (1981) was calculated by expressing the aryl and O-aryl C (110−165 ppm) as a percentage of the alkyl, O-alkyl, aryl and O-aryl C (5−165 ppm).

Results and Discussion

Concentration of humic and fulvic acids
The concentration of humic acids in each surface horizon decreased with succession from 60.4 to 30.2 C g/kg throughout the series. The concentration of fulvic acids also decreased from 21.5 to 16.2 C g/kg, but seemed almost unchanged with succession compared to humic acid concentrations. The distribution of humic and fulvic acids is shown in Figure 2. The size of pie charts indicates the relative amount of humic and fulvic acids.

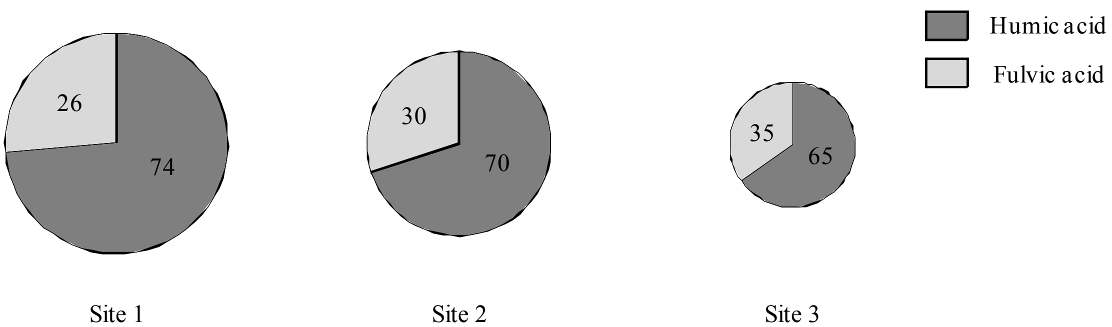

Figure 2. Distribution of humic and fulvic acid of each site.

Table 2. Distribution of carbon species in all humic and fulvic acids determined using liquid-state ^{13}C nuclear magnetic resonance spectroscopy.

	Carbonyl (220-190)	Carboxyl (190-165)	O-Aryl (165-145)	Aryl (145-110)	O-Alkyl (110-45)	Alkyl (45-10)	Aromaticity
Humic acids							
site 1	5.30	19.2	6.90	49.6	13.0	6.00	0.72
site 2	1.36	17.3	6.46	31.4	26.3	17.2	0.42
site 3	2.90	17.9	6.80	35.0	17.9	19.4	0.48
Fulvic acids							
site 1	5.15	18.8	5.54	23.8	29.3	17.4	0.34
site 2	5.62	19.1	6.72	21.1	25.5	21.9	0.31
site 3	5.37	23.3	6.74	21.6	20.5	22.5	0.33

Characteristics of humic and fulvic acids

The weight average molecular weight (*M*w) and peak average molecular weight (*M*p) of humic acids clearly increased with succession from 5.4 to 12.9 kDa and from 2.9 to 3.6 kDa, respectively. However, the number average molecular weight (*M*n) of each humic acid did not parallel the *M*w and *M*p. In contrast, the *M*w and *M*p of each fulvic acid did not appear to be correlated with succession. The ^{13}C NMR spectra of all samples showed almost the same peaks in the general chemical shift regions, but the magnitude of the peaks varied especially in humic acids. The distributions of the carbon species of all humic and fulvic acids are shown in Table 2. The proportion of aryl C notably decreased (from 49.6 to 31.4) while O-alkyl C and alkyl C proportion increased (from 13.0 to 26.3 and from 6.0 to 17.2, respectively) from site 1 to 2. There was only a slight difference not only in the aryl C proportion but also aromaticity of humic acids between sites 2 and 3 (from 31.4 to 35.0 and from 0.42 to 0.48, respectively). The changes in the composition of fulvic acids were extremely small compared to humic acids.

Conclusion

In the present study, we obtained important insights into the changes in terms of quantity and quality of humic substances in surface mineral soils (0−20 cm) in the grassland/forest ecotone of volcanic ash soil in Japan, by applying humus quantitative analysis, HPSEC analysis, and liquid-state ^{13}C NMR spectroscopy. The findings of this study clearly demonstrated that the chemical properties of humic acids, but not fulvic acids, significantly changed with decreasing aryl C content during the first 30 years of succession (site 1 vs. site 2) and then showed a continuous, though less dramatic, decrease after 100 years (site 2 vs. site 3).

References

Asakawa D, Kiyota T, Yanagi Y, Fujitake N (2008) Development and validation of method of High-Performance Size-Exclusion Chromatography (HPSEC) for various soil humic acids. *Anal Sci.* **24** (5), 607−613.

Fujitake N, Kawahigashi M (1999) ^{13}C NMR spectra and elemental composition of fractions with different particle size from an andosol humic acid, *Soil Sci. Plant Nutr.* **45,** 359−366.

Golchin A, Clark P, Baldock JA, Higashi T, Skjemstad JO, Oades JM (1997) The effect of vegetation and burning on the chemical composition of soil organic matter in a volcanic ash soil as shown by ^{13}C NMR spectroscopy. I. Whole soil and humic acid fraction. *Geoderma* **76,** 155−174.

Hatcher PG, Schnitzer M, Dennis LW, Maciel GE (1981) Aromaticity of humic substances in soils. *Soil Sci. Soc. Am. J.* **45,** 1089–1094.

Ikeya K, Watanabe A (2003) Direct expression of an index for degree of humification of humic acids using organic carbon concentration. *Soil Sci. Plant Nutr.* **49** (1), 47−53.

Shindo H, Honma H (2001) Significance of burning vegetation in the formation of black humic acids in Japanese volcanic ash soils. In 'humic substances, structures, Models and Function'. (Ed EA Ghabbour, G Davies) pp. 297−306. (Royal society of chemistry, Cambridge).

Swift RS (1996) Organic matter characterization. In 'Methods of Soil Analysis, Part 3: Chemical Method'. (Ed D Sparks, A Page, P Helmke, R Leoppert, P Soltanpour, M Tbatabai, C Johnson, M Summer) pp. 1011−1069. (Soil Sci. Soc. Am. Book Series, Soil Sci. Soc. Am., Madison).

Wada K (1986) Ando soils in Japan. Kyusyu Univ. Press, Fukuoka. 276 pp.

Effects of plantation forest species on soil properties

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Abstract
Large scale afforestation of grasslands has occurred in New Zealand. Detailed investigation of changes in soil properties over time following establishment of different tree species is necessary to understand the impacts of this land-use change on soil nutrient dynamics and availability. A field trial was established in 1999 comprising 4 replicate plots of three commercial tree species (*Pinus radiata*, *Eucalyptus nitens*, *Cupressus macrocarpa*). Soil samples were taken from each plot prior to tree planting and after 5 years growth (2004). Analyses of samples taken in 1999 showed that the topsoil (0-5 cm) had a low pH (5.1), with low to medium levels of total carbon (5.01%), nitrogen (0.43%), phosphorus (630 mg/kg), sulphur (510 mg/kg) and exchangeable base cations (7.52 $cmol_c$/kg). Results for comparison between samples taken in 1999 and 2004 revealed a decrease in total C, N, P, S and exchangeable Ca and Mg confined to the 0-5 cm soil depth. The reductions were generally greater under *P. radiata* than *E. nitens* and *C. macrocarpa*. In contrast, inorganic and plant available Olsen P levels increased under all species. These findings confirm that afforestation of grassland has a major short-term impact on soil properties and processes.

Key Words
Grassland afforestation, soil fertility.

Introduction
Recent large-scale afforestation of pastoral farmlands represents a major land-use change in New Zealand. The area under short-rotation plantation forestry (mainly radiata pine (*Pinus radiata*)) doubled from 0.9 to 1.8 million ha (c. 7% total land area) between 1985 and 2005. Most of the established forests were planted on hill country areas developed under pastoral farming, where significant accumulation of organic matter and associated nutrients (nitrogen [N], phosphorus [P], sulphur [S]) occurred in these soils as a consequence of fertiliser inputs. This change in land-use was attributed to a combination of declining returns from pastoral farming and the expectation of increased future returns from forestry. In addition to the potential economic benefits associated with the establishment of conifer plantations, development of forestry in grassland areas may help to restore degraded lands and control soil erosion, especially in hill and high country areas (Davis 1998). It is commonly believed that conifers degrade soil fertility in various ways, although there has been little consistent scientific evidence for this (Binkley 1995). However, there is evidence from studies conducted in New Zealand that there may be some short term beneficial effects associated with the change in land use from grassland to forest such as increased phosphorus availability (Davis and Lang 1991; Belton *et al.* 1995; Chen *et al.* 2003). Most afforestation studies carried out to date in New Zealand have focused on the influence of radiata pine on soil properties and processes, and have involved paired site comparisons at one point in time, commonly 15-20 years after forest establishment (Chen *et al.* 2000; Chen *et al.* 2003). Closer examination of changes in soil properties over time following establishment of different tree species is necessary to understand the mechanisms responsible for changes in the soil organic matter and nutrient availability (Binkley and Högberg 1997) which in turn will assist in the development of effective long term strategies to maintain soil quality and fertility. The specific objective of this project was to quantify the effects of the different tree species on selected soil properties 5 years after planting.

Methods
Site description
Orton Bradley Park is located near Charteris Bay on Banks Peninsula, Canterbury, New Zealand. The afforestation trial was planted in pasture on lower north-east aspect slopes on Takahe silt loam (Fragic Pallic) soil formed in greywacke loess. The altitude is 40 m and mean annual rainfall is approximately 1000 mm. The trial area consists of 900m^2 plots comprising four replicates of three species (*Pinus radiata*, *Eucalyptus nitens* and *Cupressus. macrocarpa*) arranged in a randomized block design of twelve plots each measuring 30 m x 30 m.

Soil sampling and analysis
Soil samples were taken by soil corer (6 cm diameter) at 4 depths (0-5, 5-10, 10-20, 20-30 cm) from each replicate plot immediately prior to tree planting in September 1999 and again in September 2004. Soil samples were air-dried and sieved <2 mm prior to determination of pH, total carbon (C), N, P, S, organic and inorganic P, plant-available P (Olsen P) and exchangeable cations.

Statistical analysis
Descriptive statistics and one-way ANOVA were carried out using Genstat 4.2 (Lawes Agricultural Trust, Rothamsted, UK) to calculate means and standard errors, and test for significant differences between means.

Results

Analyses of samples taken in 1999 showed that the topsoil (0-5 cm) had a low pH (5.1), with low to medium levels of organic carbon (5.01%), total N (0.434%), total P (630 mg/kg), total S (510 mg/kg) and total exchangeable base cations (7.52 $cmol_c$/kg). Comparison between samples taken in 1999 and 2004 revealed significant changes in organic matter and nutrient availability which were confined to the 0-5 cm soil depth (Table 1). The changes were generally greater under *P. radiata* than *E. nitens* and *C. macrocarpa*. For example, total C decreased by 16, 8 and 2% under *P. radiata*, *E. nitens* and *C. macrocarpa*, respectively, while corresponding decreases in total N were 17, 7 and 9%. Topsoil concentrations of organic P and total S also decreased under *P. radiata*, *C. macrocarpa* and *E. nitens* by 13, 7 and 11 and 8, 6 and 3 % respectively. In contrast, there were increases in inorganic and plant-available Olsen P in the 0-5 cm (42-62%) and 5-10 cm (62-100%) soil depth respectively. These data indicate that significant net mineralization of soil organic matter and organic N, P and S had occurred during the 5 years since tree establishment. On the other hand, soil pH levels and cation exchange capacity were largely unaffected by tree growth, while concentrations of exchangeable Ca and Mg slightly lower under all tree species in 2004 compared with 1999.

Table 1. Changes in selected topsoil (0-5 cm) properties determined prior to and five years after planting under different tree species. Data in columns are means (n=4); data in brackets are standard errors of the mean. * indicate significant differences ($P \leq 0.05$) between 1999 and 2004.

	1999	2004		
		R. pine	*E. nitens*	*C. macrocarpa*
pH	5.1 (0.04)	5.2 (0.07)	5.2 (0.09)	5.3 (0.09)
Total C (%)*	5.0 (0.13)	4.4 (0.07)	4.5 (0.20)	4.8 (0.14)
Total N (%)*	0.4 (0.01)	0.4 (0.01)	0.4 (0.02)	0.4 (0.02)
Total S (mg S/kg)*	510 (15)	445 (9)	465 (25)	458 (27)
Total P (mg P/kg)*	630 (28)	582 (39)	582 (56)	615 (64)
Inorganic P (mg P/kg)*	135 (7)	159 (6)	146 (18)	166 (17)
Organic P (mg P/kg)*	495 (22)	422 (34)	437 (38)	448 (55)
Plant-available P (Olsen P) (mg P/kg)*	13.4 (1.1)	20.8 (2.0)	16.7 (2.0)	21.6 (3.2)
Exchangeable Ca ($cmol_c$/kg)*	4.00 (0.18)	3.5 (0.12)	3.3 (0.25)	3.9 (0.28)
Exchangeable Mg ($cmol_c$/kg)*	2.8 (0.13)	2.5 (0.12)	2.7 (0.08)	2.8 (0.01)
Exchangeable K ($cmol_c$/kg)	0.4 (0.03)	0.4 (0.02)	0.5 (0.03)	0.5 (0.04)
Exchangeable Na ($cmol_c$/kg)	0.3 (0.02)	0.3 (0.03)	0.3 (0.01)	0.3 (0.05)

Conclusions

The findings of this study were consistent with previous studies, and confirmed that afforestation of grassland had a rapid and major impact on soil properties and processes. The apparent net reduction in topsoil total C and associated N, P and S can be attributed to a combination of factors including cessation of grazing, changes in organic matter and nutrient returns to soil under trees compared with grassland, and direct impacts of changes in the nature, distribution and activities of tree root systems compared with grassland.

References

Belton MC, O´Connor KF, Robson AB (1995) Phosphorus levels in topsoil under conifer plantations in Canterbury high country grasslands. *New Zealand Journal of Forest Research* **25**, 262-282.

Binkley D (1995) The influence of tree species on forest soils - processes and paterns. In 'Proceedings of the Trees and Soils Workshop'. (Eds DJ Mead, IS Cornforth) pp. 1-34 (Lincoln University Press Publishing: New Zealand).

Binkley D, Högberg P (1997) Does atmospheric deposition of nitrogen threaten Swedish forests?. *Forest Ecology and Management* **92**, 119-152.

Chen CR, Condron LM, Davis MR, Sherlock RR (2000) Effects of afforestation on phosphorus dynamics and biological properties in a New Zealand grassland soil. *Plant and Soil* **220**, 151-163.

Chen CR, Condron LM, Davis MR, Sherlock RR (2003) Seasonal changes in soil phosphorus and associated microbial properties under adjacent grassland and forest in New Zealand. *Forest Ecology and Management* **177**, 539-557.

Davis MR (1998) Soil impacts of afforestation in the high country. *New Zealand Forestry* **42**, 34-38.

Davis MR, Lang LH (1991) Increased nutrient availability in topsoils under conifers in the South Island high country. *New Zealand Journal of Forest Science* **21**, 165-179.

Glass BP (1997) A survey of afforestation intentions in New Zealand between 1996 and 2010. *New Zealand Forestry* **42**, 34-37.

Estimation of annual soil respiration rate in a larch forest in Central Siberia

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Abstract
Soil respiration is an important component process of carbon cycle in terrestrial ecosystems. The forested area of the continuous permafrost zone of Central and Northeastern Siberia exceeds that of boreal forests in other regions of the world. However, soil respiration has rarely been studied in Siberia. We conducted soil respiration rate (SR) measurement during the three growing seasons (2005–2007) and in a mid-winter by using a closed-chamber technique in a typical mature *Larix gmelinii* forest in Central Siberia. We examined micro-scale variations of SR by comparing the three dominant types of forest floor vegetation (lichen and mosses); patches of *Cladina stellaris*, *Pleurozium schreberi*, and *Aulacomnium palustre*. The daily mean SR at each period differed among the types: the values throughout the observation period (mg C/m^2/h) was the highest in *Pleurozium* (21–110), followed by *Cladina* (17–85) and *Aulacomnium* (9–68). The SR was positively correlated with soil temperature. The lowest SR in the *Aulacomnium* patch was related to higher soil moisture and lower soil temperature than the other two patches. Estimated annual SR was apparently smaller in the larch forest of Siberia than those reported for any other boreal forests.

Key Words
CO_2 flux, global warming, Russia, Gelisol, hummock, hollow.

Introduction
Soil is the major carbon pool in terrestrial ecosystems (Schlesinger and Andrews 2000). Soil respiration (SR) is an important component process (Schlesinger and Andrews 2000) of carbon cycle. SR is positively related to soil temperature in northern hemisphere temperate ecosystems (eg. Hibbard *et al.* 2005). SR is also affected by soil moisture; very high soil moisture can block soil pores (Bouma and Bryla 2000) and very low soil moisture limits microbial and root respiration (Yuste *et al.* 2003). But, in some cases, SR is not related to soil moisture (eg. Palmroth *et al.* 2005). Boreal forest in Russia plays an important role in carbon storage (Rozhkov *et al.* 1996). Larch forest in Central Siberia was characterized by low temperature and precipitation, and the presence of permafrost. Furthermore, the ground surface was characterized by low earth hummock microtopography with various lichens and mosses. So, it is considered that both soil temperature and soil moisture are very important controller of soil respiration in the region. The purpose of this study was to elucidate the effect of soil temperature and moisture on the SR related to the difference of forest floor vegetation in a larch forest in Central Siberia.

Methods
Study site
The study was conducted in Tura (64^o 12' N, 100^o 27' E), Central Siberia at the beginning of June in2005 and 2007, middle of July in 2005 and 2007, beginning of August in 2006, beginning of September in 2005, 2006 and 2007, and middle of February in 2007. The annual mean temperature and precipitation are –9.2 ^{o}C and 334 mm, respectively (Robert 1997). Soil type is Gelisol with permafrost below the depth of 70 to 100 cm from the surface and poor drainage. The soil is frozen from mid– October to the end of May. The forest consists mainly of Larch (*Larix gmelinii*) trees about 100 years old. Patches of lichens and mosses, mainly *Cladina* sp., *Pleurozium* sp., and *Aulacomnium* sp., cover the forest floor with depth of 10 to 20 cm.

Measurements of soil respiration rate (SR)
SR was measured by using a closed chamber technique according to the method of Sawamoto *et al.* (2000). Six stainless steel chambers, 25 cm height and 20 cm in diameter, were used. Each two chambers were set on patches of *Cladina stellaris*, *Pleurozium shreberi*, and *Aulacomnium palustre*. Before the measurement of SR, green parts of plants on the forest floor were cut carefully in order to exclude plant respiration. And then, the chamber collars were installed at 5 cm depth into the soil and kept overnight to eliminate the disturbance. In the following day, each 500–mL gas sample was taken into a Tedlar® bag before the chamber lid was set

up and at 6 minutes after the lid was set up. The SR was measured three times in June, and nine times in July and September in a day. Soil temperature and moisture as a volumetric water content moisture by TDR (Hydorosense[TM], Campbel Scientific Australia Phy. Ltd.) were measured at a depth of 10 cm and 0–12 cm below the surface near the chambers, respectively. CO_2 concentrations in the bags were analysed by portable gas analyser (LI–820, LICOR). The SR was calculated according to the change in CO_2 concentrations in the chamber with time by using a linear regression law.

Statistical analysis

Mean temperatures, soil moistures, and SR in each patch were calculated from 6 to 18 measurements. Two–way analysis of variance followed by Fisher's test was used to compare the means. Multiple regression analysis was conducted to explain the SR using soil temperature and moisture. The stepwise method was used for the calculation. Excel Toukei (SSRI, Japan) was used for all statistical analysis.

Results and discussion

Seasonal changes of soil respiration

As for an example, daily change of soil temperature, moisture, and soil respiration in 2005 are shown in Figure 1. Soil temperatures in each patch were highest in July (max: 13.6 °C at *Pleurozium* patch), but the soil temperature in night time decreased almost equal to that in June and September. Soil temperature in the *Aulacomnium* patch was significantly lower than that in other patches in July (6.4 °C) and September (4.4 °C). Soil moistures in each patch were higher in September than that in July (Figure 1). Soil moisture in the *Aulacomnium* patch was significantly higher than that in other patches in both July (0.31 m^3/m^3) and September (0.38 m^3/m^3). Highest SR was observed in *Pleurozium* patch in July (181 mg $C/m^2/h$). Similar tendency of the daily change was observed in other measurements (not shown). There were significant differences among the mean SR of different patches (Table 1). SR (mg $C/m^2/h$) for each patch was in the following order: *Pleurozium* (44 ± 28) > *Cladina* (34 ± 21) > *Aulacomnium* (26 ± 18). SR in winter was negligible small, but was observed (max: 1.0 mg $C/m^2/h$). Because air (–45 - –25 °C) and soil (–18.5 °C) temperature were low extremely, it is considered that CO_2 emission was occurred due to leak from deep layer, not decomposition in winter.

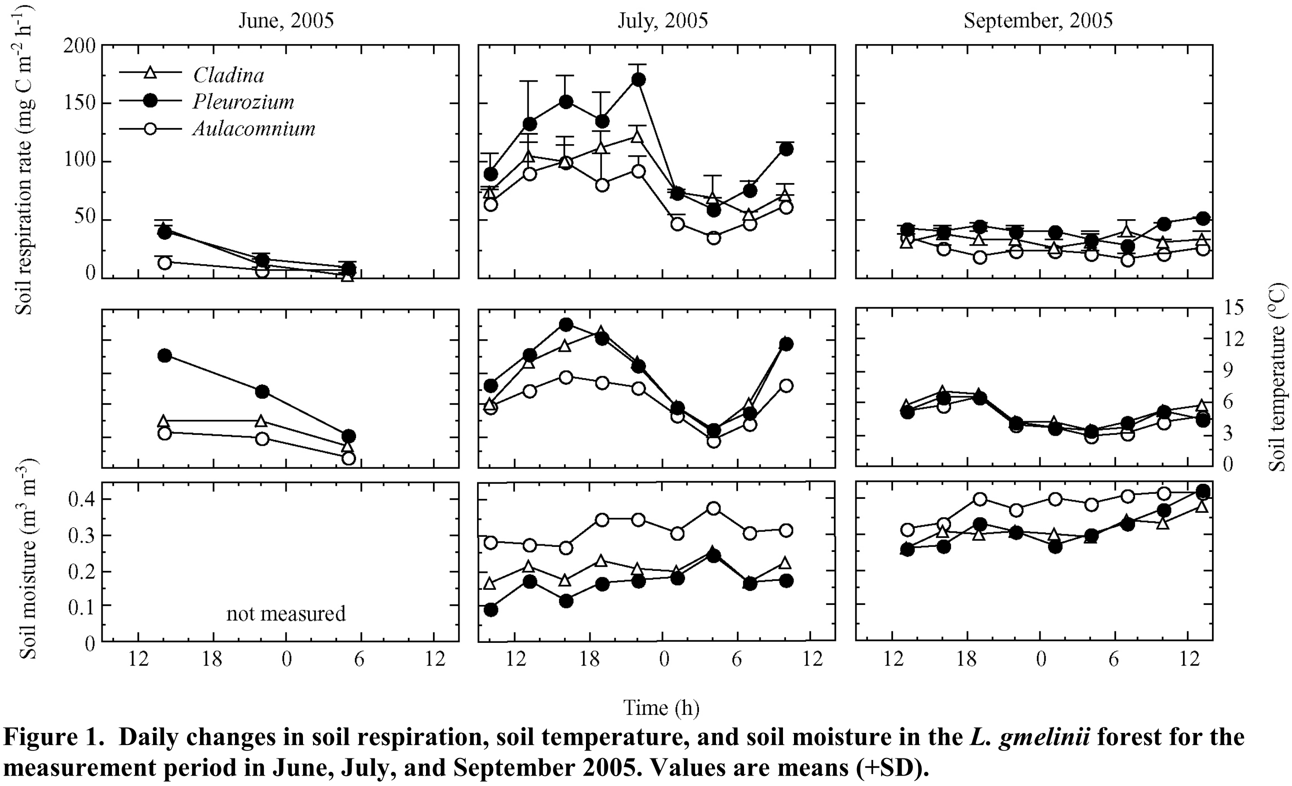

Figure 1. Daily changes in soil respiration, soil temperature, and soil moisture in the *L. gmelinii* forest for the measurement period in June, July, and September 2005. Values are means (+SD).

Relationship between SR and soil temperature and moisture

The relationship between the SR and soil temperature or soil moisture is shown in Figure 2. SR was positively correlated with soil temperature ($r = 0.71$ $P < 0.01$) (Figure 2a) and negatively correlated with soil moisture ($r = –0.57$ $P < 0.01$) (Figure 2b). It is considered that SR in *Aulacomnium* patch was smaller than other patches due to low soil temperature and high soil moisture (Table 1). *Aulacomnium* patches were relatively lower microtpography. So that, rain and melted water could be gathered in the patch and prevented to gas diffusion and to increase soil temperature. The relationship between the SR and soil temperature was somewhat different depending on the month (Figure 2a). SR in June was lower than that in any other months even if the respiration rates were compared at a similar level of soil temperature (Figure 2a). The difference suggests that yearly difference in permafrost thawing would affect the soil respiration: the organic horizon had started to thaw, but the mineral horizon was still frozen in early June. Furthermore, SR includes soil microbial respiration and plant respiration (Raich and Schlesinger 1992). Jiang *et al.* (2005) reported that root respiration was relatively higher in summer than that in spring and autumn, and Q_{10} values of SR and root respiration were different in a larch forest in north-eastern China. So that, the SR in this study might relatively lower in September than that in July due to a decrease in root respiration (Figure 3).

Table 1. Summary of soil temperature, soil moisture, and soil respiration in each patch.

	SR mg C/m^2/h		Temp. ^{o}C		Moist. m^3/m^3	
Cladina	34±21	b	4.3±2.4	a	0.36±0.14	b
Pleurozium	44±28	a	5.0±2.6	a	0.35±0.13	b
Aulacomnium	26±18	c	4.1±2.0	a	0.44±0.14	a

different letters show a significant difference among the vegetation at 5% level

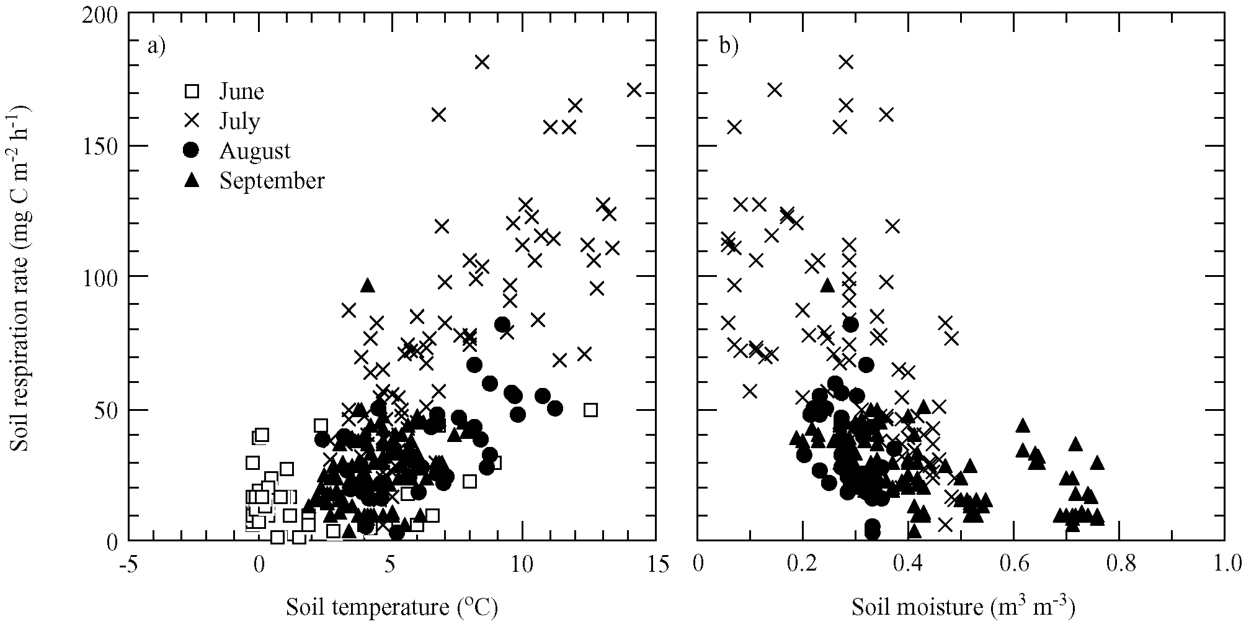

Figure 2. Relationship between soil respiration rate and soil temperature and moisture in the *L. gmelinii* forest.

Annual soil respiration rate

As mentioned in the method, soil was frozen from October to May. So that, growing season was assumed from June to September, and SR in growing season (113 g C/m^2) and winter season (11.9 g C/m^2) was calculated separately from each relationship between SR and soil temperature. The contribution of SR in winter season to annual SR estimated 9.5%. Annual SR of 125 g C/m^2 was smaller than review value of 322 ± 31 g C/m^2 (Raich and Schlesinger 1992). The value in this study was similar to that of 94 ± 16 g C/m^2 in Northern bogs and mires (Raich and Schlesinger 1992). We could not clarify the reason why, but small biomass and peculiar permafrost soil environment in our study site might be related the fact that SR is very low compared with that in other boreal forests.

Conclusion

The soil respiration rate was positively correlated with soil temperature and negatively correlated with soil moisture. The soil respiration rate was the lowest in the *Aulacomnium* patch among the patches examined. This was due to the high soil moisture and low soil temperature. The estimation of annual soil respiration rate was smaller than those previously reported in other permafrost-free boreal forests. Accumulating knowledge of the soil respiration in boreal forests in the regions of the continuous permafrost appears necessary for obtaining better estimates.

References

Bouma TJ, Bryla DR (2000) On the assessment of root and soil respiration for soils of different textures: interactions with soil moisture contents and soil CO_2 concentrations. *Plant and Soil* **227**, 215–221.

Hibbard KA, Law BE, Reichstein M *et al.* (2005) An analysis of soil respiration across northern hemisphere temperate ecosystems. *Biogeochem.* **73**, 29–70.

Jiang L, Shi F, Li B *et al.* (2005) Separating rhizosphere respiration from total respiration in two larch plantations in northeastern China. *Tree Physiol.* **25**, 1187–1195.

Palmroth S, Maier CA, McCarthy HR *et al.* (2005) Contrasting responses to drought of forest floor CO_2 efflux in a Loblolly pine plantation and a nearby Oak-Hickory forest. *Global Change Biol* **11**, 421–434.

Raich JW, Schlesinger WH (1992) The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus* **44B**, 81–99.

Rozhkov VA, Wagner VB, Kogut BM *et al.* (1996) Soil carbon estimates and soil carbon map for Russia. IIASA, WP–96–60

Sawamoto T, Hatano R, Yajima T *et al.* (2000) Soil respiration in Siberian taiga ecosystems with different histories of forest fire. *Soil Sci. Plant Nutr*. **46**, 31–42.

Schlesinger WH, Andrews JA (2000) Soil respiration and the global carbon cycle. *Biogeochem.* **48**, 7–20.

Yuste JC, Janssens IA, Carrara A *et al.* (2003) Interactive effects of temperature and precipitation on soil respiration in a temperate maritime pine forest. *Tree Physiol.* **23**, 1263–1270.

Evaluation of growth of paricá (*Schizolobium amazonicum* Huber (Duck)) in differents agroforestry systems in northeast of Pará, Brazil

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Abstract
Paricá (*Schizolobium amazonicum* Huber (Ducke)), typical of Amazon, is a important tree in reforestation due to good conditions of adaptation to associations with other species and it possesses great wood industry potential, mainly for the recovery of degraded areas. In this work, different systems of handling have been compared as a function of environmental breeding, located on experimental farms northeastern of the Pará State, Brazil: Tailândia do Pará (areas with and without addition of wood residues) and Aurora do Pará (association of Paricá with Curauá (*Ananas erectifolius*)). The methodology was visits to the field to observe the Paricá development through the collection of data (height and diameter) and collection of soil samples under the cultures for determination of fertility. In Tailândia do Pará, the culture of Paricá with addition of wood residue presented trees with bigger height (12,00 m) and diameter at breast height (24,00 cm), after 4 years of plantation, in relation to the area without addition (10,3 m and 20,00 cm, respectively). In Aurora do Pará, the culture of Paricá in association with Curauá, also presented trees with bigger height (11,5 m) and diameter (25,74 cm) in relation to the culture without this association (9,5 m and 20,36 cm, respectively).

Key Words
Rrecuperation of degraded areas, reforestation of native species, Brazilian Amazon, soil management, associations with other species, wood industry potential.

Introduction
The Amazon region represents a very important part in the environmental area to the worldwide level, due to its large tropical nature reserve, and because of deforestation for commercial purposes, contributing to the destruction of natural resources (Kato 2003). Studies on the use of agroforestry systems in conservation of the environment are being conducted in several localities in the region (Cordeiro 1999; Rodrigues 2006) showing the major social and environmental benefits from reforestation with native species and management of secondary forest to maintain productivity without any change of the ecosystem. Among the species most studied in these systems is the forestry species Paricá (*Schizolobium amazonicum* Huber (Ducke)), typical of the Brazilian Amazon, with good conditions to adapt to associations with other species, and furthermore it is a species with great wood industry potential, mainly by the recuperation of degraded areas, so it is an important tree for use in reforestation (Cordeiro 1999; Monteiro 2004). Thus, this paper focuses on studies involving the development of the species Paricá (*Schizolobium amazonicum*) in different systems of soil management and its correlation with soil quality in the areas of study.

Methodology
The main data were collected in two experimental farms, in two locations in northeastern of Pará: *Tailândia do Pará* (planting Paricá (*Schizolobium amazonicum*) in areas with and without addition of wood waste), where the planting began in 1999, so that in the beginning of the present research the reforestation was already over 4 years old, and *Aurora do Pará* (association of Paricá with Curauá (*Ananás erectifolius*)), reforestation accounts also for more than 4 years of implementation, but under a management, more specialized, with technical assistance, rotation and association of forestry species. In order to compare the different managements in terms of environmental improvement, field visits were made with relevant environmental observations in both areas, by observing the development of Paricá (visually evaluated with measurement of height with graduated scale and diameter with a caliper) and collecting samples of soil under crops for determination of soil fertility.

Results

In Tailândia for the soil recovered with waste wood, the sand fraction which is the main component (440 and 500 g/kg of soil) decreased with depth (200 g/kg of soil), a content that characterize these soils of sandy clay loam texture. The soil with waste has a lower density than those without waste, ranging from 1.19 g/cm^3 and 1.51 g/cm^3, respectively, in the horizon A. The total porosity is significantly higher in the soil with waste, ranging from 49% in the horizon A of Paricá (*Schizolobium amazonicum*) with residue to 39% in the A horizon of the Paricá without waste. In planting of Paricá with residue also has higher level of C and sum of bases. In the field, we can observe that the area that received the material had an extraordinary development in relation to the growth of the paricá, visible even to the naked eye, compared with the area where not was covered with wood waste. With regard to plant growth in the culture of Paricá, we observed that in the area where cover of sawmill residue was placed the trees had larger diameter at breast height 4 years after planting, furthermore a greater percentage (20%) of trees survived. When comparing the distribution of diameter classes in the area where sawmill residue was not applied there was a predominance of two classes (15-20 cm and 20-25 cm, with more of the latter). Moreover, in the planting without residue application there is a major variation in the diameter class of trees (10-15 cm, 15- 20 cm , 20-25 cm) (Monteiro 2004). The addition of organic material to the soil by the slow decomposition of wood favored the development of the species Paricá (*Schizolobium amazonicum*), which through the addition and incorporation into the soil of new organic material, through the fall of leaves, twigs residues and of the root system of plants (light organic material) led to the creation of an favorable environment for better vegetal development, in relation to the area that was not recovered with of wood (Table 1).

Table 1. Values of h and DAP of the *Schizolobium parahyba* var *amazonicum* (Huber ex Ducke) Barneby (Paricá) in differents planting systems.

Site	Time (months)	planting systems	h(m) (average)	DAP(cm) (average)	Increment h(m)	Increment Dap(cm)
Aurora	48	Paricá with curauá	11.5	25.74	2.05	3.0
Aurora	48	Paricá without curauá	9.5	20.36	1. 8	2.22
Tailândia	48	Paricá with addition of wood waste	12.0	24.0	2.0	2.5
Tailândia	48	Paricá without addition of wood waste	10.3	20.0	1.5	1.0

In Aurora do Pará, the area presents differents planting systems, in association with the agricultural and forestry species that investigated for recovery of degraded areas (Table 1). Those systems are agroforestry by the association between Paricá (*Schizolobium amazonicum Huber* ex Ducke), Curauá (*Ananás erectifolius* L.B. Smith), Freijó (*Cordia goeldiana* Huber), Mogno (*Swietenia macrophylla* King), among others; presenting better development of *Schizolobium amazonicum*. Here, the soils are of the Yellow Latosoil type with sandy clay texture, low organic matter content and high leaching. Low values of pH and levels of N and P. As a method of investigation of the recuperation processes, indicators were used the changes in the morphostructural conditions of the soil profiles. In relation to the results of the company Tailaminas Plac, Tailândia do Pará, it was observed that the soils covered with wood waste presented profiles with better features such as color was darker, soil was sandy, and with good drainage, compared with soils without waste application.

It was observed that the two systems have differences due to management, because the Tramontina Farm have better results despite the system has less time of implementation that in Tailândia. Since Tailândia uses waste of litter empirically in monoculture using fertilization in cultures of Paricá (*Schizolobium amazonicum*), eucalyptus (*Eucalyptus* spp) and pupunha (*Bactris gasipaes*). The physical conditions are the same; both types of soils have low organic matter and nutrients, Yellow Latosols (Monteiro 2004; Cordeiro 2005). Even so Tailândia has a good development because the trees planted in the area under coverage of waste present major growth compared to plants in the original soil. Tramontina has a management, that is more specialized, and has also technical assistance, the difference in this system is that the fertilization was made in the beginning, but now they do not use fertilizer on their crops, only doing cleaning, rotation and association of species, since it is an agroforestry system, affecting of course the economic factor, Tailândia does not yet have the economic resources necessary for technological development of the system.

The Paricá (*Schizolobium amazonicum* Huber (Ducke)) is a viable native species for recuperation of disturbed areas and with a place in the wood market, nationally and internationally. Its rapid growth and adaptation to areas with low nutrient levels allows it to be optimum in agroforestry systems (Cordeiro 1999), being the second plant species used in reforestation in the state of Para (Cometti 2005). The species

Schizolobium amazonicum shows better results due to the influence of soil preparation, in this case the Tramontina farm, furthermore, by use of agroforestry practice and technical assistance. It presents an improvement of physical and chemical properties of soil and major response of trees in those areas with wood waste that shows that the Paricá responds to good management practices.

Conclusions

The Paricá (*Schizolobium amazonicum* Huber (Ducke)) is a viable native species for recuperation of disturbed areas and with a role in the wood market, nationally and internationally. Its rapid growth and adaptation to areas with low nutrient levels allow it to be optimum in agroforestry systems, being the second plant species used in reforestation in the state of Para. The species *Schizolobium amazonicum* shows better results in the treatments where influence soil preparation, in this case the Tramontina farm, furthermore, by agroforestry practice and technical assistance present. It presents an improvement of physical and chemical properties of soil and major development of the trees in those areas with wood waste that shows that the Paricá responds to good management practices.

References

Cordeiro IMCC (1999) 'Performance diferencial de crescimento da espécie *Schizolobium amazonicum* Huber (Ducker) em sítios degradados sob diferentes regimes de Preparação de área na microregião do Guamá, Aurora do Pará, Pará'. (UFPA: Núcleo de Altos Estudos Amazônicos, Belém, Pará, Brasil).

Cordeiro IMCC (2005) 'Comportamento das espécies Paricá (*Schizolobium amazonicum* Huber ex Ducke) e Curauá (*Ananas erectifolius* L.B Smith) em diferentes sistemas de cultivo, Aurora do Pará, Pará.' (UFRA: Belém, Pará, Brasil).

Cometti JL (2005) 'Gestão de Resíduos de madeira como cobertura orgânica do solo em culturais florestais, Tailândia do Pará, Pará'. (UEPA: Belém, Pará, Brasil).

Monteiro KFG (2004) 'Utilização de resíduos de madeira como cobertura no solo: o estudo de caso de um sistema agroflorestal no estado do Pará'. (UFRA: Belém, Pará, Brasil).

Rodrigues RC (2006) 'Biomassa Microbiana e Acúmulo de Liteira em SAF´s a formação com Meliáceas.' (UFRA: Belém, Pará, Brasil).

Kato MSA (2003) 'Tecnologias para melhoria dos sistemas de produção da agricultura familiara com base no manejo de capoeiras na amazônia, com ênfase em alternativas ao uso de fogo'. (EMBRAPA-CPATU: Belém, Pará, Brasil).

How an advanced combination of soil science, biogeochemistry, and paleo-ecology helps Ecuadorian cloud forest management

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Abstract
Montane forest composition and specifically the position of the upper forest line (UFL) is very sensitive to climate change and human interference. As a consequence, reconstructions of past altitudinal UFL dynamics and forest species composition are instrumental to infer relationships between climate change and vegetation dynamics, and assess the impact of (pre)historic human settlement. We developed an innovative combination of techniques derived from soil science, molecular organic geochemistry, palynology, and vegetation ecology to reconstruct past forest dynamics from fossil pollen and biomarkers preserved in soils and peat deposits. Here we present the results of the first application of the new approach to reconstruct the natural position of the UFL in a biodiversity hotspot of montane rainforest in the Ecuadorian Andes where its location is highly disputed. Our results show that the current páramo vegetation above 3600 m in the area is a natural ecosystem rather than the product of deforestation. As a consequence, Kyoto Protocol triggered reforestation activities in this part of the Ecuadorian Andes should be limited to maximally 3600 m elevation. Aforestation at higher elevations will disturb the natural páramo ecosystem and affect the carbon storage potential of the soil.

Key Words
Reforestation, upper forest line dynamics, biomarker analysis, pollen analysis, pedogenesis.

Introduction
The highest parts of the tropical Andes in Ecuador consist of fragile ecosystems characterized by a high biodiversity. They are mainly inhabited by indigenous populations that entirely rely on subsistence use of the natural resources. The ecosystems in these high montane areas include páramo grasslands and humid montane rain (and cloud) forests, which originally covered large tracts from Venezuela to Peru. These ecosystems fulfill important environmental functions e.g. supply of drinking and irrigation water, biodiversity conservation, carbon storage, agricultural production and tourism. Over the past decades, population pressure on the systems in question has rapidly increased and agricultural land use has strongly expanded, often using inappropriate techniques and leading to rampant degradation. Natural upper montane forests have been widely replaced by either potato cultivation or tree plantations (Hofstede *et al.* 2002), and native páramo grasslands are over-exploited by grazing and burning. In many situations the intense land use is believed to have lead to a downward push of the upper forest line (UFL: defined as the elevation with the highest occurrence of continuous forest). However, upward movements of montane forest have also been attributed to global warming, particularly affecting mountain ecosystems (Price 1999). Contradictory results from fossil pollen analysis on the one hand and vegetation analysis on the other have resulted in scientific debate about the natural position of the UFL in the Ecuadorian Central Valley. In the Guandera Biological Station that protects one of the last remaining stretches of cloud forest in the Inter-Andean Central Valley, scientific estimates of the natural position of the UFL ranged from the present day position of approximately 3600 m a.s.l. *(above sea level)* to a hypothesized 4000 m a.s.l. (Laegaard 1992; Wille *et al.* 2002). Such uncertainty is severely hindering sustainable management of the remaining stretches of cloud forest, including reforestation projects under Kyoto Protocol CO_2 emission trade schemes. The main aim of the five year program “Reconstruction of the Upper Forest Line in Ecuador (RUFLE)” that was concluded in 2009, was to obtain better insight into forest dynamics in the Ecuadorian Andes in general under biotic and a-biotic pressures, and in particular to reconstruct the most likely natural position of the UFL in the northern Andes. To overcome the scientific uncertainty an interdisciplinary multi-proxy approach was chosen. In this

approach an innovative combination of techniques derived from soil science, molecular organic geochemistry, palynology, and vegetation ecology was set up to identify the spatio-temporal vegetation dynamics along series of altitudinal transects that cross current and past forest-páramo transitions.

Methods

The study area

The study area is part of the Guandera Biological Reserve in El Carchi province in northern Ecuador. The Reserve is located approximately 11 km from the town of San Gabriel in the Eastern Cordillera. It protects approximately 10 km^2 of high altitude páramo grassland as well as extensive areas of relatively undisturbed montane cloud forest. Most of the Andean forest is left between 3300 and 3640 m elevation. Above an altitude of 3640 m grass páramo dominates the landscape but some forest patches occur up to 3700 m altitude. The soils in the study area were formed in three distinct tephra deposits of Holocene age (Tonneijck *et al.* 2008). They consist of Histosols with andic properties at sites currently covered by continuous forest, Andic Cambisols in forest patches above the UFL and Andosols at the sites currently covered by páramo vegetation (Tonneijck *et al.* 2009). In addition to soils, two peat deposits in the area were sampled and analysed. Vegetation in the study area was thoroughly analysed and described as part of the project (Moscol Olivera and Cleef 2008a,b).

Soil analysis

All soils sampled were extensively described, chemically and physically analysed and ^{14}C dated (Tonneijck *et al.* 2008; Tonneijck and Jongmans 2008; Tonneijck *et al.* 2006). A micro-morphological assessment of bioturbation features formed an important part of the analyses with an aim of obtaining the chronostratigraphy of the soils (Tonneijck and Jongmans 2008). For this, thin sections were analysed using a Leitz M420 makrozoom microscope and a Leitz Wetzlar petrographic microscope. Thin sections were described following the micro-morphological terminology of Stoops (Stoops 2003). Abundance classes were as follows: very few (< 5%), few (5 – 15%), common (15 – 30%), frequent (30 – 50%), dominant (50 – 70%) and very dominant (> 70%).

Analysis of molecular biomarkers

In the biomarker approach, plant species typical for specific vegetation zones are examined for the presence of biomarkers, defined as plant-specific (combinations of) molecular components. The most likely candidates for application as biomarker to distinguish forest from non-forest vegetation were *n*-alkanes, *n*-alcohols and *n*-fatty acids in the carbon number range of C_{20}-C_{36} that uniquely occur in the wax layers of leaves and in roots of higher plants in varying combinations. Along the altitudinal transect the plant species responsible for the dominant biomass input in soils were sampled and several intact soil monoliths collected. The lipids from the plant and soil samples were extracted and analyzed with a combination of Accelerated Solvent Extraction (ASE) and gas chromatography-mass spectrometry (GC/MS) optimized for this purpose (Jansen *et al.* 2006a). Plant lipids were tested for unique combinations of *n*-alkanes, *n*-alcohols and *n*-fatty acids through cluster analysis using Ward's method (Jansen *et al.* 2006b). To unravel the mixed soil lipid signal with depth, a discrete linear model (VERHIB) was developed that describes the accumulation of lipids in the soil. By inversion the most likely vegetation composition leading to the mixed biomarker signal in the soil was derived (Jansen *et al.* 2009).

Fossil pollen analysis

From the same soil samples used to establish the biomarker signal, fossil pollen were extracted and analysed. In addition, the modern pollen rain in the area was sampled. All samples were processed using the standard pre-treatment including sodium pyrophosphate, acetolysis, and heavy liquid (bromoform) separation (Faegri and Iversen 1989). To calculate pollen concentration values, one tablet of exotic *Lycopodium* spores was added to each sample prior to processing. Pollen samples were mounted in glycerin gelatin and counted with a Zeiss microscope at 500x magnification. For identification, pollen morphological descriptions published by Bogotá *et al.* (1996) and Hooghiemstra (1984), and the modern pollen reference collection at Amsterdam laboratory were used. A minimum of 400 pollen grains from terrestrial taxa was counted for all samples. The data were plotted and cluster analysis was carried out with TILIA, TILIAGRAPH, CONISS and TG-view (Bakker *et al.* 2008).

Results

Figure 1 provides an example of the percentage forest cover (all forest species grouped together) as reconstructed from biomarkers and fossil pollen from a soil monolith at 3480 m a.s.l. in a site currently part of the continuous forest. From Figure 1 it is clear that fossil pollen and molecular biomarkers both point to the same trends in forest cover with time. However, important differences are also visible as for instance at 55 cm depth where the biomarkers indicate a much more pronounced shift in percentage forest cover that also peaks slightly earlier than indicated in the pollen record. The reason is that as a result of the wind blown dispersal of pollen, the pollen record yields a regional image of shifts in vegetation patterns. In contrast, due to their leaf origin, biomarkers provide a much more local picture. Most likely, the peak at 55 cm indicates a local phenomenon such as nearby páramo patches within the integral forest that also occur at present day (Moscol Olivera and Cleef 2008b) and are predominantly reflected in the local biomarker record. The steady and concurrent decline in percentage forest cover from 20 cm upward might be interpreted as a decline in UFL position, but given the distance of the site from the current UFL and the local nature of the biomarker record, it more likely reflects deforestation coupled with encroaching agricultural fields from the valley below the current forest. These results illustrate how the multi-proxy approach when we subsequently applied it in the complete sequence of soils and peat deposits, allowed for a reconstruction of past dynamics of forest vegetation patterns with unprecedented detail. A reconstruction where the regional scale vegetation dynamics obtained from fossil pollen and present day vegetation patterns e.g. (Bakker *et al.* 2008; Moscol Olivera and Cleef 2008a; Moscol Olivera and Cleef 2008b) was complemented with the local scale information yielded by biomarker analysis (Jansen *et al.* 2008; Jansen *et al.* 2009). Not only did this allow us to reconstruct the altitudinal shifts of the UFL over time, the combined data also provided detailed information about changes in forest composition over time, often at species level. The study of pedogenetic processes allowed for an assessment of the maximum attainable resolution of the fossil pollen and biomarkers preserved in soils. In addition, it provided the time frame for the vegetation reconstructions and served as proxy to distinguish between forest and páramo vegetation through its organic matter composition (Tonneijck and Jongmans 2008). From our combined results we infer that during the last 10,000 years the UFL in the study area did not reach altitudes above 3700 m.

Figure 1. The percentage forest cover over time reconstructed from biomarkers (solid line) and fossil pollen (dotted line) from a soil monolith at 3480 m a.s.l. within the current integral forest at the Guandera research site.

Conclusion

We conclude that the multi-proxy approach developed offers a valuable new tool to reconstruct past forest dynamics in general and in particular UFL positions within areas with volcanic ash soils where its natural location is uncertain due to human interference, climate change or both. With respect to the uncertainty whether the present-day páramo vegetation in the Guandera Biological Station has a natural background or is the result of human induced deforestation, we conclude that the natural undisturbed UFL was below 3700 m and páramo vegetation above 3600 m is a natural ecosystem. As a consequence, Kyoto Protocol triggered reforestation activities in this part of the Ecuadorian Andes should be limited to maximally 3600 m elevation. Afforestation above 3600 m, in particular with exotic trees such as *Eucalyptus* and Mexican pine (mainly *Pinus patula* and *P. radiata*), should be strongly discouraged. Not only from a conservational point of view, but also because it will affect the carbon storage potential of the soil.

References

Bakker J, Moscol M, Hooghiemstra H (2008) Holocene environmental change at the upper forest line in northern Ecuador. *The Holocene* **18**, 877-893.

Bogotá RG, Lamprea SJ, Rangel JO (1996) Atlas palinológico de la clase Magnoliopsida en el páramo de Monserrate. *El Páramo Ecosistema a Proteger* **2**, 131-191.

Faegri K, Iversen J (1989) Textbook of pollen analysis. (Wiley: Chichester)

Hofstede RGM, Groenendijk JP, Coppus R, Fehse JC, Sevink J (2002) Impact of pine plantations on soils and vegetation in the Ecuadorian High Andes. *Mountain Research and Development* **22**, 159-167.

Hooghiemstra H (1984) Vegetational and climatic history of the High plain of Bogotá, Colombia. (J. Cramer: Vaduz)

Jansen B, Haussmann NS, Tonneijck FH, Verstraten JM. De Voogt P (2008) Characteristic straight-chain lipid ratios as a quick method to assess past forest - páramo transitions in the Ecuadorian Andes. *Palaeogeography Palaeoclimatology Palaeoecology* **262**, 129-139.

Jansen B, Nierop KGJ, Kotte MC, De Voogt P, Verstraten JM (2006a) The application of Accelerated Solvent Extraction (ASE) to extract lipid biomarkers from soils. *Applied Geochemistry* **21**, 1006-1015.

Jansen B, Nierop KGJ, Hageman JA, Cleef A, Verstraten JM (2006b) The straight-chain lipid biomarker composition of plant species responsible for the dominant biomass production along two altitudinal transects in the Ecuadorian Andes. *Organic Geochemistry* **37**, 1514-1536.

Jansen B, Van Loon EE, Hooghiemstra H, Verstraten JM (2009) Analysis of plant biomarkers greatly improves reconstruction of palaeo-environments. *Palaeogeography Palaeoclimatology Palaeoecology* (accepted).

Laegaard S (1992) Influence of fire in the grass páramo vegetation of Ecuador. In 'Páramo, an Andean ecosystem under human influence'. (Eds H Balslev, JL Luteyn) pp 151-170. (Academic Press: London)

Moscol Olivera MC, Cleef AM (2008a) A phytosociological study of the páramo along two altitudinal transects in northern Ecuador. *Phytocoenologia* **39**, 79-107.

Moscol Olivera, MC, Cleef AM (2008b) Vegetation composition and altitudinal distribution of montane rain forests in northern Ecuador. *Phytocoenologia* **39**, 175-204.

Price M (1999) Global Change in the Mountains. (Parthenon: New York)

Stoops G (2003) Guidelines for analysis and description of soil and regolith thin sections. (Soil Science Society of America Inc: Madison, WI)

Tonneijck FH, Hageman JA, Sevink J, Verstraten JM (2008) Tephra stratification of volcanic ash soils in Northern Ecuador. *Geoderma* **144**, 231-247.

Tonneijck FH *et al.* (2009) Carbon stocks and stabilization mechanisms in volcanic ash soils under natural upper montane forest and grassland in northern Ecuador. *European Journal of Soil Science* (accepted).

Tonneijck FH, Jongmans AG (2008) The influence of bioturbation on the vertical distribution of soil organic matter in volcanic ash soils: a case study in northern Ecuador. *European Journal of Soil Science* **59**, 1063-1075.

Tonneijck FH, Van der Plicht J, Jansen B, Verstraten JM, Hooghiemstra H (2006) Radiocarbon dating of soil organic matter fractions in Andosols in Northern Ecuador. *Radiocarbon* **48**, 337-353.

Wille M, Hooghiemstra H, Hofstede R, Fehse J, Sevink J (2002) Upper forest line reconstruction in a deforested area in northern Ecuador based on pollen and vegetation analysis. *Journal of Tropical Ecology* **18**, 409-440.

Impact of forest soil compaction on soil atmosphere composition

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Abstract
Soil compaction has become an important issue for forest soil sustainability because the increasing timber demand and the mechanization of all silvicultural operations have led to a higher traffic level. Soil compaction causes a physical degradation which in turn disrupts many other functions e.g. wood production, biodiversity, greenhouse gas emission, surface water quality. Two experimental sites were designed in the North-East of France to study the changes of soils subject to heavy traffic by forest machinery, on the short and the long-term. These sites are representative of highly soils sensitive to compaction. They present the same general functioning (neoluvisol), but they differ on some physical (strength, bulk density, clay content) and chemical properties (pH, chemical saturation). The soil atmosphere composition is directly impacted by soil compaction (change of voids volume, size and connection) but also indirectly by change of other soil properties like water content, temperature and biological activity. On the two sites, we observed a decrease in O_2 concentration and an increase in CO_2 concentration due to traffic, especially during wet periods. The change of soil atmosphere composition will probably impact root growth, gas emissions, microbial and faunal activity and probably have a negative feedback on soil recovery dynamic.

Key Words
Soil compaction, soil gases.

Introduction
The general mechanization of forest operations and the increase of wood demand has resulted in an increase in physical damages to soils. Soils subject to heavy traffic will deform until equilibrium between external forces and the counter-forces of the soil is reached which mainly depends on soil intrinsic characteristics determining the soil sensitivity and on soil moisture. Therefore, soil compaction induces changes in the volume, the size and the continuity of voids (Soane and Van Ouwerkerk 1994, Rohand *et al.* 2004; Shestak and Busse 2005; Lamandé *et al.* 2005). These physical modifications will more or less impact transfer processes (water, gas, heat) and consequently soil oxygenation and flooding. Soil flora, fauna and microbial activity will be constrained with a negative feedback on the dynamics of soil restoration. The consequences of heavy traffic on soil are often interdependent and few studies have tackled the issue of the changes of a compacted forest soil on the long-term considering all the functions impacted.
As soil deformation under wheel tracks damages the pore system and increases the volume of soil occupied by water (Shestak and Busse 2005), the aeration status of the soil will be disturbed (Von Wilpert and Schäffer 2005) and soil respiration rate will change. Consequently the composition of its atmosphere may change significantly (Soane and Van Ouwerkerk 1994). Simojoki *et al.* (1991) cited by Soane and Van Ouwerkerk (1994) and Mac Afee *et al.* (1989) cited by Soane and Van Ouwerkerk (1994) observed a significant diminution in O_2 concentration due to soil compaction. The presence of gas like CH_4, N_2O, H_2S or H_2, even in low concentration, is an indicator of restricted soil aeration and its oxygenation status (Soane and Van Ouwerkerk 1994). For example, Teepe *et al.* (2004) recorded enhanced N_2O emissions from compacted soils. The aims of this study were to monitor changes in soil atmosphere composition following the traffic of forest machinery on the short and long-term and to determine the relation between the succession of restricted / well-aerated periods with the other parameters influenced by heavy traffic (soil structure, water content, temperature). The underlying questions were –i- how and how much are the functions and functioning of forest soils affected by compaction? and –ii-how long does it take to restore soil functions and functioning after heavy traffic?

Methods
Two experimental sites have been set up in Lorraine (NE part of France). They are located in the "Hauts-Bois" forest - Azerailles (48° 29′ 19″ N, 6° 41′ 43″ E), Meurthe et Moselle, and in the "Grand Pays" forest - Clermont en Argonne (49° 06′ 23″ N, 5° 04′ 18″ E), Meuse. Each site was clear-cut and timber (*Fagus*

sylvatica, *Quercus petraea* mainly) were extracted with a cable yarding system to avoid damaging the soil. Afterwards a forwarder drove on the soil only for an equivalent of two travels in spring 2007 in Azerailles (AZ) and in spring 2008 in Clermont en Argonne (CA). The tyres of the forwarder measured 600/55 * 26,5 and were inflated to a pressure of 350 kPa. Its total weight was 21 to 25 tonnes. The sites of Clermont en Argonne and Azerailles have an elevation of 270m and 300m respectively. The climate of the region is characterised by a 30-year mean annual temperature of 9°C (Azerailles) to 9,5 °C (Clermont en Argonne) and a 30-year annual precipitation of 900 mm (Azerailles) to 1000mm (Clermont en Argonne).

The soil of both sites is classified as a neoluvisol (WRB 1990) and is developed on a silt layer of approximately 40-50 cm based on a clayey layer (textural breaking causing a temporary water logging). The soil of both sites is hence considered as highly sensitive to compaction and some chemical and physical differences between the two sites may influence the behaviour and restoration after compaction allowing to identify their main causes. The soil of the Azerailles site has a pH varying between 4.6 and 5.2 along the profile with 22, 56 and 22 % of clay, silt and sand respectively from the surface to a depth of 30-40 cm and with 30 to 60, 32 to 50 and 8 to 18 % of clay, silt and sand from 30-40 cm to 1m depth. Whereas the soil pH of the Clermont en Argonne site varies between 4.4 and 5.1 along the profile, with 13, 72 and 15 % of clay, silt and sand respectively from the surface to a depth of 30-40 cm and with 21 to 33, 54 to 65 and 13 to 14 % of clay, silt and sand from 30-40 cm to 1m depth.

The whole site area (about 5 ha) was split in three blocks to control site variability. The sites were instrumented to monitor numerous parameters, measured at different time and spatial scales to understand how the soil is degraded and how theses parameters interact. One block was equipped for investigations in i-climate (rainfall, air temperature, air saturation index), ii soil climate e.g. Soil moisture using TDR system (Time Domain Reflectometry) and soil temperature using sensors inserted at different soil depth (15, 30 and 60 cm in the undisturbed plot, 10, 25 and 55 cm in the compacted plot, 5 replicates per depth * treatment). The sites were also equipped with piezometers distributed on the whole site area with some of them (10 in CA and 12 in AZ) fitted with sensors recording every 4 hours the water table level and the others being measured once a month. The soil gases were collected once a month in Azerailles from 42 gas collectors (5 depths * 3 blocks * 2 treatments + 2 * 1 depth * 1 treatment * 2 blocks + 5 * 1 depth * 1 block * 2 treatment) and in Clermont en Argonne from 32 gas collectors (5 depths * 3 blocks * 2 treatments + 2 * 1 depth * 1 treatment * 2 blocks). Each collector is composed of a tube that connects a subsurface soil air equilibration port and a sampling port at the soil surface. The gas collectors were inserted into the soil at different depths (10, 25, 35, 50 and 70 cm for the undisturbed plots; 7, 15, 25, 40 and 60 cm for the compacted plots), in the control plot (C) the depth of the gas collector is roughly always 10 cm above the depth of the equivalent one in the compacted plot (T), to account for the volume loss in the compacted one.

Results

The forwarder traffic led to an increase in bulk density of 26% and 17% compared to the initial values in the first 10 cm in AZ and in CA respectively. This impact decreased with soil depth but was still significant at 60 cm depth. The changes in water content and temperature through the year differed also between treatments, but the effect of compaction on soil moisture and temperature depended on the season, the depth and the site considered.

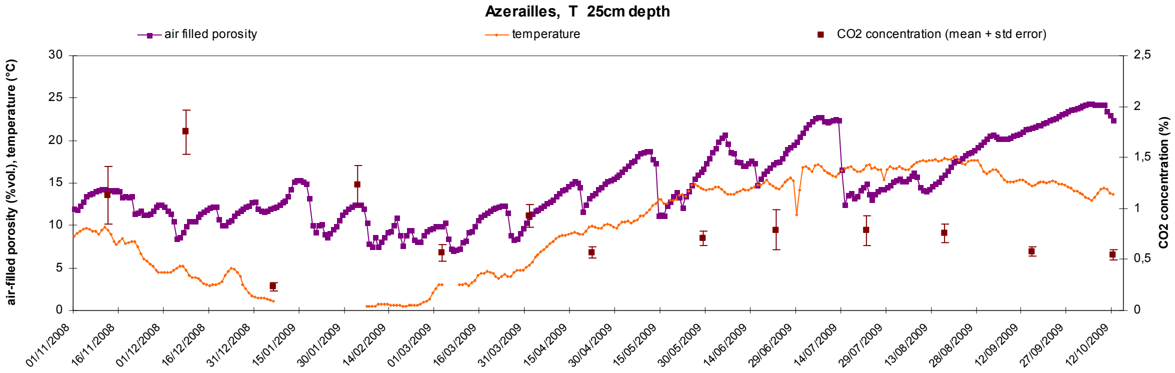
The composition of soil atmosphere was highly variable within the same plot (1 site * 1 block * 1 treatment) probably due the high site variability of water table level, water content and physical parameters (bulk density, hydraulic properties, air permeability). Nevertheless some general patterns could be drawn:

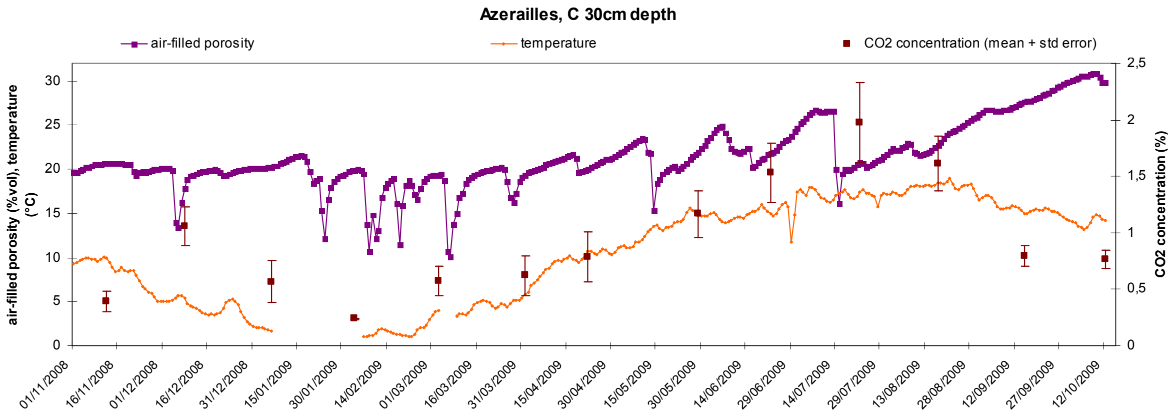
-During wet periods, O_2 concentration in the compacted plots was lower than in the undisturbed plots and CO_2 concentration was higher in the compacted plots than in the undisturbed ones.
-In CA CO_2 concentration was always more important in the compacted plots than in the undisturbed ones, even during dry periods. Besides, the amplitude of the impact of soil compaction on O_2 and CO_2 concentrations varied among sites, but as they weren't compacted at the same date, it is too early to draw some conclusions from these different amplitudes.

-In AZ no CH_4 could be found in the soil atmosphere whereas in CA some CH_4 occurred at least during the first year after compaction (in AZ the gas collector were installed one year after compaction, in CA they were installed 2 months after compaction).

-In AZ the atmosphere of the undisturbed soil had a higher N_2O concentration than the one of the compacted soil. In CA it was exactly the opposite situation.

In AZ the 5 gas collectors per treatment inserted at the same depth and near the moisture and temperature sensors, allowed investigations on the relations between soil physical properties affected by compaction and soil atmosphere composition. For example, the two following figures display the data collected from these 10 gas collector. They show that CO_2 concentration was lower in the C-treatment only from December 2008 to April 2009, period where the air-filled porosity was far lower in the compacted T-treatment than in the C-treatment. However, even if the air-filled porosity remained more or less lower in the T-treatment from April 2009 to October 2009, the CO_2 concentration of the C-treatment became higher than in the T-treatment in that period. Two hypothesis can be made to explain these observations; -i- the respiration was more important in the C-treatment than in the T-treatment where the biological activity was probably most of the year anaerobic and –ii- when the compacted soil dries it cracks more than the undisturbed soil allowing faster gas exchange between the soil and the atmosphere (phenomenon observed when measuring the air permeability of the soil as a function of soil water content, data not shown).





Conclusions
The traffic of forest machinery has an impact on soil atmosphere composition which depends on many other factors also affected by soil compaction. Consequently it is important to monitor on the long term all the soil properties impacted by soil compaction to understand how soil functions change and interact. For example, in Azerailles CO_2 emissions were measured at the same time as the sampling of soil gas and near the gas collectors (F.Parent and D.Epron, EEF, Nancy University). The results show that CO_2 emissions throughout the year were lower in the compacted plots than in the control plots although soil atmosphere displayed higher CO_2 concentrations in the compacted plots during wet periods and in the undisturbed plots during dry periods.

References

Lamandé M, Ranger J, Lefevre Y (2005) ‘Effets de l'exploitation forestière sur la qualité des sols’. (Les dossiers forestiers: 15, O.N.F., Paris).

Rohand K, Al Kalb A, Herbauts J, Verbrugge JC (2004) Changes in some mechanical properties of a loamy soil under the influence of mechanized forest exploitation in a beech forest of central Belgium. *Journal of Terramechanics* **40,** 235-253.

Shestak CJ, Busse MD (2005) Compaction alters physical but not biological indices of soil health. *Soil*

Science Society of America Journal **69,** 236-246.
Soane BD, Van Ouwerkerk C (1994) 'Soil Compaction in Crop Production'. (Amsterdam: Elsevier science: BV).
Teepe R, Brumme R, Beese F, Ludwig B (2004) Nitrous oxide emission and methane consumption following compaction of forest soils. *Soil Science Society of America Journal* **68,** 605-611.
Von Wilpert K, Schäffer J (2006) Ecological effects of soil compaction and initial recovery dynamics: a preliminary study. *European Journal of Forest Research* **125,** 129-138.

Impact of tree species on the distribution of amorphous silica in an acid brown soil

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Abstract
Biogenic silica (BSi) precipitates in leaves and needles of trees and contributes to the amorphous silica fraction (ASi) in soil through litterfall. In forest ecosystem, the ubiquitous and significant ASi pool could influence the Si mass-balance at watershed scale, which plays a major in the global biogeochemical processes. Thus, an accurate quantification of the ASi pool in forest soils is a mandatory step. Here, we examined the distribution of the ASi in an acid brown soil under various tree species (Douglas fir, Black pine and European beech) established in identical soil and climate conditions. We quantified the ASi concentration in soil with alkaline extraction (Na_2CO_3 0.1M). The mean content of ASi in humus layer significantly decreases in the sequence (mg ASi / g): Douglas fir (14.5) > European beech (11.8) > Black pine (5.4). Tree species impacts the ASi pool in the humus layer through different uptakes of $H_4SiO_4^0$ and accumulation of BSi in leaves and needles. In mineral layers, pedogenic processes could hide tree species impact on ASi concentration, which decreases from the humus layer to 15 cm depth and then progressively increases from 15 to 75 cm depth under each three species. In soil, the distribution of the ASi content seems rather influenced by translocation-dissolution, pedogenic opal formation and ASi sorption onto Fe oxides. Our data imply that forest ecosystem type impacts the stock of BSi in a soil-tree system.

Key Words
Silicon cycle, phytoliths, pedogenesis, temperate forest.

Introduction
Silicon (Si), the second mass abundant element of the crustal Earth (Wedepohl 1995), plays a major role in global biogeochemical processes. The continental cycle of Si strongly impacts the oceanic biogeochemical cycle of Si, as land-ocean fluxes contributes to more than 80% of the input of dissolved Si (DSi) in the oceans (Tréguer *et al.* 1995). Terrestrial plants largely contribute to the DSi pool since their annual biogenic silica (BSi) production ranges from 60 to 200 Tmol year^{-1} (Conley 2002), which rivals BSi production of diatoms in oceans (240 Tmol year^{-1}) (Tréguer *et al.* 1995). Besides the primary crystalline silicates and the secondary clay minerals, soil also contains an amorphous silica (ASi) fraction having both pedogenic (Wada *et al.* 1989) and biogenic (BSi) origins (Drees *et al.* 1989). As the solubility of ASi is an order of magnitude higher than the one of the crystalline silicate minerals (Fraysse *et al.* 2009), amount of ASi in soils could influence the release of DSi in soil solutions and the export to the hydrosphere. An accurate quantification of the ASi pool in soils is a mandatory step to better understand the Si mass-balance at watershed scale. ASi pool in forest soil is likely impacted by tree species, because Si uptake by vegetation and return of BSi to soil are tree species-dependent (Cornelis *et al.* 2010). However, the influence of tree species on ASi pool has not been measured yet. There is a variety of methodology used for extracting ASi from soils (Sauer *et al.* 2006). Among them, Saccone *et al.* (2007) prove that alkaline methods are adequate to dissolve ASi fraction in soils. Here, we isolate the impact of tree species on the distribution of ASi since soil physical and chemical properties were identical between tree plots when the experimental site was set up. Then, our study aims to evaluate the relative impact of Si recycling by forest tree species on the ASi concentration in a temperate forest soil.

Methods
The experimental site is located at Breuil-Chenue (Nièvre-Morvan, France). Over the period 2001-2006, the mean annual rainfall is 1212 mm and the mean annual temperature is 9 °C. The acid brown soil is classified as an Alumnic Cambisol (IUSS 2006) and is developed from granite very poor in major cations (0.5% MgO, 0.6% CaO and 4.4% K_2O). The native mixed forest (oak and European beech) was clear-cutted in 1976 and replaced by monospecific plots of Douglas fir, Black pine and European beech.

Phytoliths was extracted form leaves and needles through digestion at 120 °C in a concentrated HNO_3 (70 %) / H_2O_2 (30 %) mixture.

In this study, the alkaline solution (Na_2CO_3 0.1 mol l^{-1}, pH = 11.2) was applied to extract ASi in forest soil samples. The wet alkaline method is based on the fact that the solubility of ASi is strongly enhanced at pH above 9. Corrections for the simultaneous amorphous and crystallize dissolution of Si have been made using time course extractions (DeMaster 1981; Saccone *et al.* 2007). Here, approximately 30 mg of dried soil (< 2 mm) was mixed in 40 ml of alkaline solution and digested at 85 °C during 5 hours. One milliliter was removed from the extraction solution after 15, 60, 120, 180, 240 and 300 minutes and was neutralized with 9 ml of 0.022 mol l^{-1} HCl. DSi was determined by ICP-AES. Under the extraction conditions, we assume that (i) most ASi dissolved completely within the first 2 hours of the extraction and (ii) alumino-silicates released Si at a constant rate over the whole extraction time. Extracted SiO_2 (mg g^{-1}) was plotted versus time and ASi concentration was estimated extrapolating the linear part to zero time (intercept value on Y-axis) following the theoretical curve to correct for continuous crystalline silicates dissolution (DeMaster 1981; Saccone *et al.* 2007).

Results

Figure 1 shows that the ASi content in the humus layer was affected by tree species. The mean content of ASi (mg SiO_2 g^{-1}) in humus layer significantly decreased in the sequence: Douglas fir (14.5±0.65) > European beech (11.8±0.30) > Black pine (5.4±0.31). Between 0 and 7.5 cm soil depth, the content of ASi was significantly higher under European beech than under Douglas fir and Black pine. At the other soil depth, there was no significantly difference between tree species. The ASi distribution with depth shows very similar trend under each tree species: a decrease of the ASi pool from the humus layer to 15 cm depth and a slight increase from 15 to 75 cm depth.

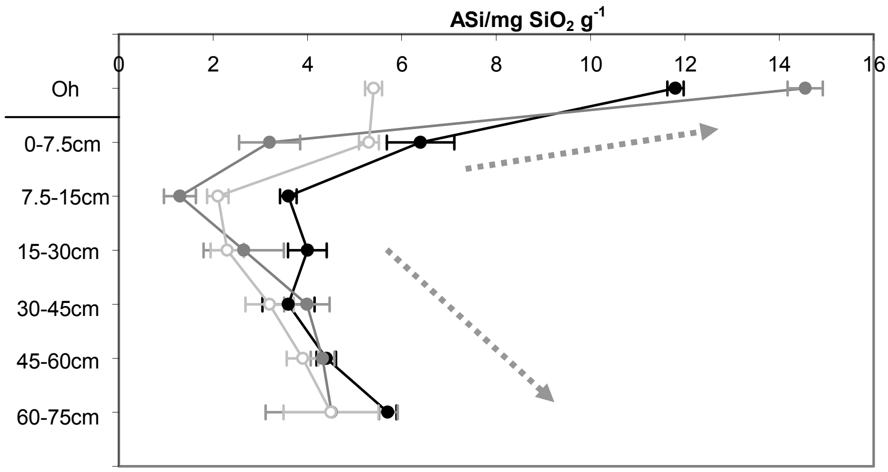

Figure 1. Mean ASi concentration in humus (Oh) and soil layers, expressed as mg SiO_2 g^{-1} of dry matter.The ASi content is evaluated by wet alkaline dissolution (Na_2CO_3 0.1 mol l^{-1}) under European beech (black), Douglas fir (grey) and Black pine (white). The error bar (n = 3) represents the standard error.

In our sample, we assume that ASi pool includes biogenic and pedogenic opal as well as ASi sorption onto Fe oxides but not short-range ordered silicates such as allophane and imogolite because the acidic conditions in the humus layer (pH (H_2O) = 4 - 4.76) and the aqueous speciation of Al and Si.

Conclusion

In identical soil and climate conditions, Cornelis *et al.* (2010) prove that the annual Si uptake is clearly dependent on tree species, decreasing in the sequence: Douglas fir (30.6±8.0 kg ha^{-1} yr^{-1}) > European beech (23.3±6.5 kg ha^{-1} yr^{-1}) > Black pine (2.3±0.9 kg ha^{-1} yr^{-1}). This study also reveals that, at least, 83% of the Si uptake is annually recycled on topsoil through litterfall. Thus, tree species impacts the ASi pool in organic horizons through various Si uptake and restitution on topsoil. The decrease of the ASi content between humus layer and 15 cm depth, may be due to the translocation and dissolution of phytoliths followed by root-uptake and/or leaching. Between 15 and 75 cm depth, the slight increase of the ASi content is probably due to the translocation-accumulation of stable phytoliths, precipitation of pedogenic opal and ASi sorption onto Fe oxides.

Thus, we demonstrate that tree species impacts the ASi stock in the humus layer through various Si recycling. The tree's root uptake influences the Si soil-solution equilibrium and subsequently dissolution of poorly crystalline and non crystalline inorganic soil components. Trees act both as a source (BSi restitution) and a sink (Si uptake) of dissolved Si in soil solution. More than 30 years after plantation, the ASi concentration in soil is influenced by the Si recycling but also by pedogenic processes. In our temperate and granitic environment, the study of the relative contribution of small ASi pool and large crystalline silicates pool on the dissolved Si need more consideration.

References

Conley DJ (2002) Terrestrial ecosystems and the global biogeochemical silica cycle. *Global Biogeochemical Cycles* **16 (4)**, GB1121, doi:10.1029/2002GB001894.

Cornelis JT, Ranger J, Iserentant A, Delvaux B (2010) Tree species impact the terrestrial cycle of silicon through various uptakes. *Biogeochemistry* **97**, 231-245.

DeMaster DJ (1981) The supply and accumulation of silica in the marine environments. *Geochimica et Cosmochimica Acta* **45**, 1715–1732.

Drees LR, Wilding LP, Smeck NE, Sankayi AL (1989) Silica in soils: quartz and disordered silica polymorphs. In 'Minerals in Soil Environments' (Eds JB Dixon, SB Weed) pp. 913-974. (Soil Science Society of America Book Series No. 1, Madison, WI).

Fraysse F, Pokrovsky OS, Schott J, Meunier JD (2009) Surface chemistry and reactivity of plant phytoliths in aqueous solutions. *Chemical Geology* **258**, 197-206.

Sauer D, Saccone L, Conley DJ, Herrmann L, Sommer M (2006) Review of methodologies for extracting plant-available and amorphous Si from soils and aquatic sediments. *Biogeochemistry* **80**, 89–108.

Saccone L, Conley DJ, Koning E, Sauer D, Sommer M, Kaczorek D, Blecker SW, Kelly EF (2007) Assessing the extraction and quantification of amorphous silica in soils of forest and grassland ecosystems. *European Journal of Soil Science* **58**, 1446–1459.

Tréguer P, Nelson DM, Van Bennekom AJ, De Master DJ, Leynaert A, Quéguiner, B (1995) The silica balance in the world ocean: a reestimate. *Science* **268**, 375-379

Wada K (1982) Allophane and imogolite. In 'Minerals in Soil Environments' (Eds JB Dixon, SB Weed) pp. 1051-1087. (Soil Science Society of America Book Series No. 1, Madison, WI).

Wedepohl KH (1995) The composition of the continental crust. *Geochimica et Cosmochimica Acta* **59**, 1217-1232.

Impacts of nitrogen additions and harvest residue management on chemical composition of soil carbon in a plantation forest

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Abstract
Soils are the major pool of terrestrial C globally that, if carefully managed, can be used to offset rising atmospheric CO_2. An important consideration for the forestry sector is how forest management practices might impact on the forest soil C stock. An experiment has been set up to determine how long-term fertilisation and harvest residue management will affect soil C stocks and the relative abundance of biochemically resistant compounds in soil organic C. The early results suggested that soil C concentration has not been affected by fertilisation and harvesting methods. The following results were achieved in the light fraction of soil organic matter (SOM): long-term fertilisation increased alkyl C and alkyl-to-O-alkyl ratio; the abundance of cutin-derived compounds was greater in fertilised soil C than in non-fertilised soil C; major carbohydrates (mannose, glucose and sucrose) decreased in the fertilised plot despite greater forest litter inputs. Also, in the light fraction of SOM, the stem only harvesting treatment had a greater amount of cutin-derived compounds and carbohydrates, compared with whole tree harvest treatment. The project will eventually lead to a better understanding of forest management impacts on both quantity and quality of soil C in New Zealand forests.

Key Words
Soil organic matter, carbon chemical composition, NMR, forest plantation.

Introduction
Soils are the major pool of terrestrial C globally that, if carefully managed, can be used to offset rising atmospheric CO_2 (Lal 2005). Forest soils make up about 30 % of soil organic C in terrestrial ecosystems (Jandl *et al.* 2007). In New Zealand, an important consideration for the forestry sector is how forest management practices might impact on forest soil C stock to meet Kyoto Protocol requirements. An increase in nitrogen (N) due to long-term fertilisation is predicted to increase forest productivity (Smith *et al.* 1994; Smith *et al.* 2000), whereas whole tree harvesting can generally reduce second rotation forest productivity (Walmsley *et al.* 2009). However, on average, soils contain three times as much C as terrestrial vegetation. Thus if changes in N availability or forest harvesting methods alter soil C turnover, net C sinks or sources from increased or decreased forest growth could be significantly enhanced or reduced, depending on the direction of the soil responses. Soil organic compounds are made up of different pools which vary in their turnover time or rate of decomposition. The labile soil organic compounds, such as proteins and carbohydrates, turn over relatively rapidly (< five years), whereas biochemically resistant compounds, such as lipids from leaf cuticles and roots and lignin from woody tissues, are expected to remain stable throughout 10- to 100-yearl timescales. Unfortunately, considerable uncertainty remains concerning which soil organic matter (SOM) structures are likely to be accumulated or degraded in forest ecosystems under the increased N availability or from the changed inputs of harvesting slash and litter. The sensitivities of SOM decomposition to soil N availability or change in litter input in forest ecosystems are critical for modelling changes in soil C stock.

Methods
The trial site is located in Berwick forest, Dunedin of New Zealand and is part of an intensive harvesting long-term soil productivity research program. A second rotation *Pinus radiata* D. Don plantation was planted in 1990. Sixteen 400 m^2 plots were established with each treatment plot surrounded by a 10-metre buffer zone. Half of the treatment plots received regular N applications (urea) between 1990 and 1999 with total N addition of 95 g/m^2. Two different organic matter removal treatments were also established by using different harvesting techniques (stem only and whole tree harvesting) during the first rotation harvest. These two treatments, combined with the presence or absence of fertiliser, produced four different treatment combinations, replicated four times. All treatment plots were weeded manually at establishment, and herbicide was applied to suppress weed growth until canopy closure.

Soils were sampled at 15 random points within each plot in March 2009 using a 25 mm diameter corer at three depth intervals (0-5, 5-15 and 15-25 cm). The 15 soil cores collected from each treatment plot were thoroughly mixed, air-dried and sieved (2 mm mesh) to remove stones, roots and other extraneous material. Soil moisture content was determined from a sub-sample dried at 100 °C. Another sub-sample was ground thoroughly into a fine powder before chemical analyses. For most analyses, the soils were separated into light and heavy fractions by floating soils in NaI (density < 1. 65 g/cm^3). The concentrations of C and N were determined with a Leco Corporation CNS-2000 Elemental Analyser. The chemical composition of SOC was analysed by CPMAS ^{13}C NMR. Carbohydrates, cutin and suberin compounds and lignin monomers were extracted by solvent extraction, base hydrolysis and copper oxidation, respectively, and analysed by gas chromatography/mass spectrometry.

Table 1. Mean C and N concentrations and C:N ratio in mineral soil (< 2 mm) under different treatments in a second-rotation *Pinus radiata* plantation, Berwick, New Zealand. Means were based on four replicate values per treatment. F: long-term N-fertilised; NF: not fertilised; SO: stem only harvesting plots and WH: whole tree harvesting plots.

	Total C (%)			Total N (%)			C:N ratio		
	0-5 cm	5-15 cm	15-25 m	0-5 cm	5-15 cm	15-25 cm	0-5 cm	5-15 cm	15-25 cm
NF+SO	5.65	2.70	1.83	0.27	0.15	0.11	20.67	18.04	16.63
NF+WH	5.05	2.78	1.70	0.24	0.14	0.10	20.42	19.88	17.00
F+SO	5.19	2.74	1.84	0.28	0.15	0.11	19.22	17.85	16.22
F+WH	5.30	2.53	1.97	0.27	0.14	0.13	19.63	17.68	15.53

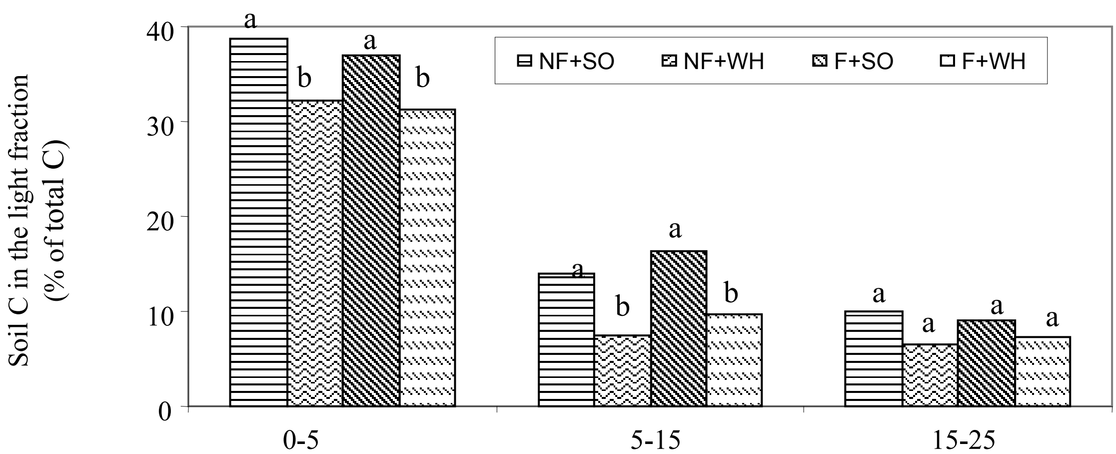

Figure 1. Soil C in the light fraction (density < 1.65 g/cm^3) in mineral soil (< 2 mm) under different treatments in second-rotation *Pinus radiata* plantation forest, Berwick, New Zealand. For the same soil depth, means followed by the same letter are not significantly different (P < 0.05).

Results and discussion

Early results suggested that fertilisation and harvest residue management had no significant effect on the C and N concentrations in 0-25 cm mineral soils. It is evident that addition of N to soils had a tendency to decrease soil C:N ratio, however, the difference in soil C:N ratio between fertilisation and non-fertilisation treatments was only marginally significant at P < 0.1. Harvest residue management did not significantly impact soil C:N ratios in 0-25 cm mineral soils (Table 1).

Although C concentrations in the mineral soils were not significantly affected by fertilisation and harvest residue management, the percentage of light fraction in soil C of the 0-15 cm depth was significantly altered by harvest residue management, however not by fertilisation (Figure 1). The chemical composition of light fraction C in different soils as revealed by CPMAS ^{13}C NMR was generally similar. The largest compound class in the light fraction soils was O-alkyls, ranging between 33.3% and 36.6%. Aromatics represented the next largest group. Long-term fertilisation increased the relative enrichment of alkyl C and alkyl-to-O-alkyl ratio in the light fraction of soil organic matter, which may suggest an increased decomposition of light fraction (Mendham *et al.* 2002; Mathers *et al.* 2003; Huang *et al.* 2008) and, as a result, an increased relative resistance of soil C due to fertilisation (Table 2). Compared with whole tree harvest plots, stem only harvest plots also showed a greater alkyl-to- O-alkyl ratio in the light fraction of soil organic matter, however the difference due to harvest residue management was smaller than that from fertilisation.

Table 2. Relative signal distributions (%) in the solid-state CPMAS ^{13}CNMR spectra of light fraction of mineral soils (0-5 cm) under different treatments in a second-rotation *Pinus radiate* plantation forest. Values are single determinations of composite samples from four replicate plots, each of 12 replicate cores.

	Alkyls	N-alkyls	O-alkyls	Aromatics	Phenolic	Carboxyl C	A/O ratio
NF+SO	16.9	9.1	35.6	26.4	5.8	6.3	0.47
NF+WH	14.6	8.2	36.6	26.7	6.5	7.4	0.40
F+SO	19.5	10.1	34.6	24.8	5.3	5.8	0.57
F+WH	17.8	9.8	33.3	25.1	6.0	8.2	0.53

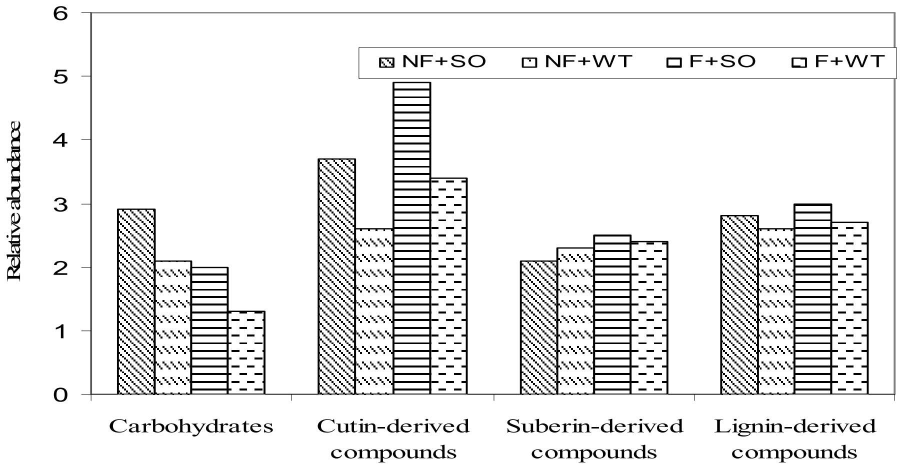

Figure 2. Relative abundance (mg/100mg OC) of major SOM components in 0-5 cm mineral soils subjected to different treatments.

The abundance of cutin-derived compounds was greater in the light fraction of fertilised soil C than in that of non-fertilised which may indicate the reduced decomposition of cutin-derived compounds after fertilisation. Alternatively, increased growth of trees due to N fertilisation may increase leaf litter production that contributes to increased cutin inputs into the light fraction of soil (Smaill *et al.* 2008b). Cutin-derived compounds originate from the waxy coating of leaves and are believed to be recalcitrant. The result from GC/MS is consistent with that from ^{13}C-NMR (Figure and Table 2). The stem only treatment had a greater amount of cutin-derived compounds in the light fraction of soil, compared with whole tree harvest treatment. This may also be attributable to the increased leaf litter. Major carbohydrates (mannose, glucose and sucrose) in the light fraction of soil decreased in the fertilised plot despite greater inputs from forest litter. This observation is consistent with the studies of Neff *et al.* (2002), in which carbohydrates are considered to be among the most labile constituents of the light fraction of SOM and their decomposition is accelerated by fertilisation. The carbohydrate abundance in the light fraction of SOM was lower in whole tree harvest plots than in the log only plots. This may be due to the decreased input from plant litter (Figure 2).

Conclusion

In the first step of the research, the chemical compositions of soil C in light fraction were identified. The results suggest long-term fertilisation may lead to an increased decomposition of light fraction and an increase in percentage of aliphatic C.

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References

Huang Z, Xu Z, Chen C, Boyd S (2008) Changes in soil carbon during the establishment of a hardwood plantation in subtropical Australia. *For. Ecol. Manage*. **254,** 46-55.

Jandl R, Lindner M, Vesterdal L, Bauwens B, Baritz R, Hagedorn F, Johnson DW, Minkkinen K, Byrne KA (2007) How strongly can forest management influence soil carbon sequestration? *Geoderma* **137,** 253-268.

Lal R (2005) Forest soils and carbon sequestration. *For. Ecol. Manage*. **220,** 242-258.

Lorenz K, Lal R, Preston CM, Nierop KGJ (2007) Strengthening the soil organic carbon pool by increasing contributions from recalcitrant aliphatic bio(macro)molecules. *Geoderma* **142,** 1-10.

Mathers NJ, Xu ZH (2003) Solid-state C-13 NMR spectroscopy: characterisation of soil organic matter under two contrasting residue management regimes in a 2-year-old pine plantation of subtropical Australia. *Geoderma* **114,** 19-31.

Mendham DS, Mathers NJ, O'Connell AM, Grove TS, Saffigna PG (2002) Impact of land-use on soil organic matter quality in south-western Australia - characterisation with C-13 CP/MAS NMR spectroscopy. *Soil Biol. Biochem.* **34,** 1669-1673.

Neff J, Townsend A, Gleixner G, Lehman S, Turnbull J, Bowman W (2002) Variable effects of nitrogen additions on the stability and turnover of soil carbon. *Nature* **419,** 915-917.

Smaill S, Clinton P, Greenfield L (2008a) Postharvest organic matter removal effects on FH layer and mineral soil characteristics in four New Zealand *Pinus radiata* plantations. *For. Ecol. Manage.* **256,** 558-563.

Smaill S, Clinton P, Greenfield L (2008b) Nitrogen fertiliser effects on litter fall, FH layer and mineral soil characteristics in New Zealand *Pinus radiata* plantations. *For. Ecol. Manage.* **256,** 564-569.

Smith CT, Dyck WJ, Beets PN, Hodgkiss PD, Lowe AT (1994) Nutrition and productivity of *Pinus Radiata* following harvest disturbance and fertilisation of Coastal Sand Dunes. *For. Ecol. Manage.* **66,** 5-38.

Smith CT, Lowe AT, Skinner MF, Beets PN, Schoenholtz SH, Fang SZ (2000) Response of radiata pine forests to residue management and fertilisation across a fertility gradient in New Zealand. *For. Ecol. Manage.* **138,** 203-223.

Walmsley JD, Jones DL, Reynolds B, Price MH, Healey JR (2009) Whole tree harvesting can reduce second rotation forest productivity. *For. Ecol. Manage.* **257,** 1104-1111.

Lignin phenols and cutin- and suberin-derived aliphatic monomers as biomarkers for stand history, SOM source, and turnover

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Abstract
Each tree species has a unique chemical composition, and also various tree tissues differ in their chemistry. Analysis of lignin phenols and cutin- and suberin-derived aliphatic monomers was employed to investigate wheter their composition can be traced back after decay and transformation into soil organic matter (SOM) to study SOM source, degradation, and stand history.

The composition of bound lipids and lignin compounds in leaves/needles and root material of different tree species and of grasses was analyzed using copper (II) oxide (CuO) oxidation, saponification and subsequent analysis by gas chromatography/mass spectrometry (GC/ MS). The aim was to examine the applicability of these compounds in soils and different density and particle size fractions as biomarkers for the respective tree species and the grass. In contrast to lignin, aliphatic molecules derived from suberins and cutins were preferentially preserved in horizons and soil fractions with mean residence times > 250 years. The pattern of cutin and suberin monomers in the soils and fractions changed with increasing ^{14}C age, but alteration of these aliphatic macromolecules resulted in less degradable structures which are still indicative for the respective plant species.

Key Words
Saponification, CuO oxidation, lipids, forest trees, gas chromatography/mass spectrometry.

Introduction

The composition of lignin components is different for angiosperm, gymnosperm and grass lignin. Leaf cutins and suberin found in barks and roots of different plants are known to exhibit plant specific chemical compositions (Goñi and Hedges 1990). Moreover, laboratory and field degradation studies indicated that degradation processes are not uniform for all lignin, suberin and cutin monomers, but that some constituents are preferentially degraded (Kögel-Knabner *et al.* 1989; Otto and Simpson 2006).
In the present study, the amount and composition of lignin, cutin and suberin in grassland and forest soils stocked with different tree species and selected density and particle size fractions were investigated. The objectives were to analyze, if (i) cutin and suberin monomers are useful biomarkers for the contribution of root-vs. shoot derived OC to SOM in different soil horizons and fractions, (ii) if monomer-specific turnover kinetics during decay and transformation into SOM hinders the identification of plant- and tissue-specific lignin, cutin and suberin signatures or offers additional information about the degradation status of the SOM and (iii) if lignin, cutin and suberin are useful biomarker for vegetation history.

Methods

Study sites, soils and soil sampling

We sampled nine sites at two different study areas in Germany: The National Park Bayerischer Wald, an area with granite, gneiss and quarternary deposits (mainly gneiss debris) parent material, and a pre alpine loess region. A more detailed description of the sites is given in Table 1. Soils were classified according to IUSS Working Group Reference Base 2006. At every site we sampled three randomly distributed soil pits and analyzed the samples from the replicates separately. At each site, leaves or needles, roots, bark and fresh litter were sampled. The forest floor and mineral topsoil horizons of all soil profiles and selected subsoil horizons were collected for chemical analyses.

Table 1. Parent material, soil types, recent and former vegetation of the nine study sites.

Region and Parent material	Soil type	Former vegetation	Recent vegetation
National Park Bayerischer Wald			
Granite	Leptic Entic Podzols (Skeletic)	Norway spruce	Norway spruce
Granite	Leptic Entic Podzols (Skeletic)	Norway spruce	Grass (approx. 25 yr.)
Quarternary deposits	Leptic Cambisols (Dystric, Skeletic)	Norway spruce	Norway spruce
Quarternary deposits	Leptic Cambisols (Dystric, Skeletic)	Norway spruce	Grass (approx. 25 yr.)
Quarternary deposits	Leptic Cambisols (Dystric, Skeletic)	European beech	European beech
Pre alpine loess region			
Loess	Cutanic Alisols (Humic, Siltic)	Norway spruce	Norway spruce
Loess	Cutanic Alisols (Humic, Siltic)	Norway spruce	European beech (approx. 80 yr.)
Loess	Cutanic Alisols (Humic, Siltic)	Norway spruce	Douglas fir (approx. 80 yr.)
Loess	Cutanic Alisols (Humic, Siltic)	Norway spruce	Sessile oak (approx. 80 yr.)

Density and particle size fractionation

Selected A and B horizons were subjected to a two-step density fractionation with Na polytungstate solution with a density of 1.6 g/cm^3 and subsequent particle size fractionation to obtain the free light fraction (fLF) and the occluded light fraction (oLF). After complete dispersion by ultrasonication (450 J/ml), the fractions 2 to 20 µm (silt), and <2 µm (clay) with their respective heavy fraction (HF) were obtained.

Determination of organic carbon (OC) concentration

The concentration of OC was determined for all ground plant samples, bulk soil samples, density, and particle-size separates in two replicates with an Elementar Vario EL analyzer by dry combustion at 950 °C. Since all soil samples were free of carbonate, the measured total C concentration was equivalent to the OC concentration.

Biomarker extraction and analysis

Previous to isolation of bound lipids, and lignin-derived phenols, solvent extraction was used to remove free lipids and other solvent extractable compounds. (Otto *et al.* 2005). Cutin- and suberin-derived monomers were extracted from the samples using a base hydrolysis method (Otto and Simpson 2006). Lignin phenols were extracted using CuO oxidation as described in Otto and Simpson (2006). Before analysis by Gas Chromatography/Mass Spectrometry (GC/MS), extracts were derivatized to convert compounds to trimethylsilyl derivatives (Otto and Simpson 2006).

Statistical analysis

We tested each lignin, cutin, and suberin monomer, and summarized substance groups and selected compound ratios for its suitability to classify cutins vs. suberins, or to differentiate among different tree species and grass or among fresh and highly degraded SOM. Therefore, the data were subjected to discriminant analyses. For this purpose, a set of cases with known group membership was used for each analysis as a training set in order to select the best discriminating variables. Subsequently, factor analysis was used to group variables with discriminant coefficients > 0.5 and similar information in order to reduce the amount of model variables.

Results

Cutin and suberin monomers as biomarkers for the contribution of aboveground vs. belowground OC input

The base hydrolysis of soil and vegetation samples yielded a series of aliphatic and phenolic compounds corresponding to previously reported compositions of hydrolysates from grassland and forest soils (Kögel-Knabner *et al.* 1989; Otto and Simpson 2007). The sources of some compounds, which are found in animal, plant, and fungal membranes are unspecific (Otto and Simpson 2007). Nevertheless, our statistical analysis identified eight variables which discriminated significantly between cutin and suberin based on their structural units (Table 2). The eight variables where subsequently subjected to a factor analysis which resulted in two factors with an eigenvalue >1 (Figure 1). High loadings for factor a are indicative for cutin/aboveground input, whereas high loadings for factor b are indicative for suberin/belowground input.

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Table 2. Variables with discriminant coefficients > 0.5 for discrimination between cutin (aboveground plant input) and suberin (belowground plant input).

Variable	Discrimination coefficient	Occurrence in suberin	Occurrence in cutin
Σ hydrolysable phenols	0.63	Common	-
Σ n-alkan-1-ols	0.64	Common	-
Σ n-alkanoic acids	0.57	Common	-
Σ Long-chain ω-hydroxyalkanoic acids	0.77	Common	-
Σ Long-chain α,ω-diacids	0.63	Common	-
9,10-epoxy-C_{18} α,ω dioic acid	0.56	Common	Rare
Σ Mid-chain hydroxy C_{14}, C_{15}, C_{17} acids	0.77	-	Common
Σ C_{16} Mono- and dihydroxy acids and diacids	0.53	Rare	Common

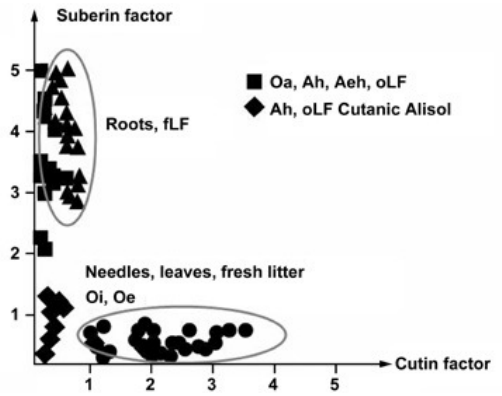

Figure 1. Factor space between factor a (grouping variables indicative for cutin) and factor b (grouping variables indicative for suberin).

Lignin, cutin and suberin monomers as biomarkers for SOC degradation status

Discrimination analysis identified seven variables which discriminated significantly between groups of samples with different degradation status of the OM (Table 3). Most of them are ratios, indicating a preferential degradation of some lignin, cutin and suberin constituents compared to other compounds. High discrimination coefficients of the ω-$C_{16}/\Sigma C_{16}$ ratio and the ω-$C_{18}/\Sigma C_{18}$ ratio are consistent with findings of Goñi and Hedges (1990), which reported that cutin acids containing double bonds or more than one hydroxyl group are preferentially degraded compared to ω-hydroxyacids in marine sediments. The ratio between mid-chain-substituted acids to total cutin and suberin acids (ΣMID/ΣSC) generally decreases with increasing degradation status of the SOM, from plant samples to the forest floor horizons.

Increasing lignin degradation is reflected by larger acid/aldehyde ratios for both vanillyl and syringyl units. The faster turnover of syringyl-type compared to vanillyl-type lignin is reflected by the lower discrimination coefficient of the Ac/Al_S ratio compared to the Ac/Al_V ratio.

Table 3. Variables with discriminant coefficients > 0.5 for discrimination between groups of samples with different degradation status

Variable	Discrimination coefficient	Change during degradation
ω-$C_{18}/\Sigma C_{18}$	0.76	Increases with degradation
ω-$C_{16}/\Sigma C_{16}$	0.72	Increases with degradation
ΣMID/ΣSC	0.64	Decreases with degradation
Ac/Al_V	0.82	Increases with degradation
Ac/Al_S	0.60	Increases with degradation
S/V	0.64	Decreases with degradation
9,10,18-trihydroxy octadecanoic acid	0.79	Increases with degradation

Lignin, cutin and suberin monomers as biomarkers for recent vegetation and vegetation history

Twelve variables were initially selected by discriminant analysis for the discrimination among the four different tree species and the grass vegetation. However, the first training set, which was applied to choose those variables which significantly contribute to a vegetation-specific signature, only consisted of fresh plant material, topsoil horizons and light fractions with recent ^{14}C ages. Then the twelve variables were subjected to a factor analysis which resulted in three factors with an eigenvalue >1 (Figure 2a). The factor space between factors a and b significantly differentiated between soil samples from sites which are stocked with

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different angiosperm species, whereas the factor space between factors b and c differentiated between samples from sites with different gymnosperm species.

Subsequently, we tested the established factors and the discrimination coefficients of the twelve variables for a larger data set, including subsoil horizons and heavy fractions with mean residence times > 250 years. However, only 39% of all cases of this larger test set were classified correctly. Thus, we repeated the discriminant analysis for the larger data set. This time 19 variables were selected by discriminant analysis, including also degradation products of cutin and suberin monomers. Those 19 variables were again grouped into three factors with an eigenvalue >1 (Figure 2b). Two lignin variables (S/V ratio and C/V ratio) were selected by the discriminant analysis with the first data set. In contrast no lignin variables were selected by the discriminant analysis with the second data set including the subsoil horizons and old fractions. This is probably due to the fact that lignin compounds in the subsoil are strongly degraded and have lost source-specific functional groups.

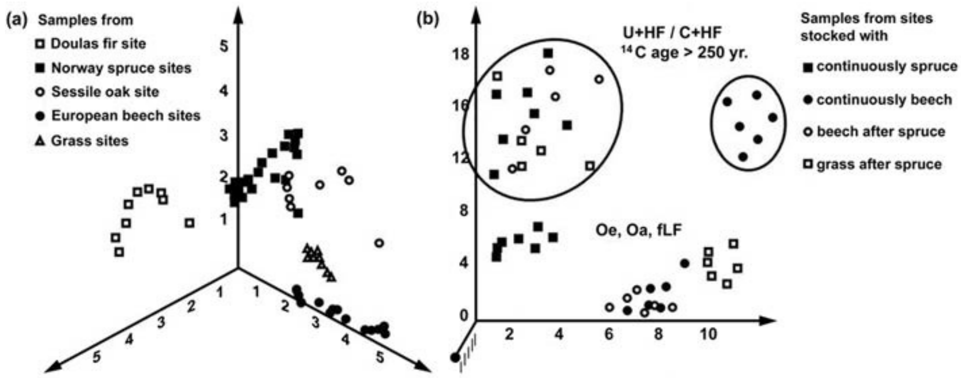

Figure 2. (a) Factor analysis with data set consisting of fresh plant material and soil samples with recent ^{14}C ages; (b) factor analysis with data set including soil samples and fractions with ^{14}C ages > 250 years.

Summary and Conclusion

The analyses of bound lipids and CuO oxidation products of fresh plant material, soils and different density and particle size fractions of sites stocked with Norway spruce, Douglas fir, European beech, Sessile oak or grasses showed that cutin and suberin are useful biomarkers to differentiate between root- vs. shoot input. In combination with lignin, cutin and suberin signatures of the soil and density/particle size fractions also provided important information about the degradation status of the SOM. Sites with different recent vegetation differed in their lignin, cutin and suberin signature of the young SOM and the light fraction; sites with similar former forest stands showed similar cutin and suberin signatures of old SOM and the heavy fraction. In contrast to cutin and suberin, lignin phenols were inappropriate as biomarkers for vegetation history. In summary, this study was able to prove that cutin and suberin are compounds with a high diagnostic value for root- vs. shoot-derived input, recent vegetation and vegetation history.

References

Goñi MA, Hedges JI (1990) The diagenetic behaviour of cutin acids in buried conifer needles and sediments from a coastal marine environment. *Geochimica and Cosmochimica Acta* **54,** 3083-3093.

IUSS Working Group WRB (2006) World reference base for soil resources 2006. World Soil Resources Reports 103. FAO, Rome.

Kögel-Knabner I, Ziegler F, Riederer M, Zech W (1989) Distribution and decomposition pattern of cutin and suberin in forest soils. *Zeitschrift für Pflanzenernährung und Bodenkunde* **152,** 409-413.

Otto A, Simpson MJ (2006) Sources and composition of hydrolysable aliphatic lipids and phenols in soils from western Canada. *Organic Geochemistry* **37,** 385-407.

Otto A, Simpson MJ (2007) Analysis of soil organic matter biomarkers by sequential chemical degradation and gas chromatography – mass spectrometry. *Journal of Separation Science* **30,** 272-282.

Otto A, Shunthirasingham C, Simpson MJ (2005) A comparison of plant and microbial biomarkers in grassland soils from the Prairie Ecozone of Canada. *Organic Geochemistry* **36,** 425-448.

Long-term changes in a forested Spodosol

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Abstract
Soil formation results from the interaction of climate, relief, parent material, organisms, and time. Most soil genesis and weathering experiments are short-term and focus on addressing a single factor, with experiments to evaluate time rare. We utilized an existing long-term soil-bag experiment in central Maine, USA (Spodosols). Soil-bags containing homogeneous C horizon placed beneath the forest floor or in the middle of the B horizon for 17 years were compared with archived samples for changes in total C, N, S, and P. In addition, soil pH, exchangeable cations, and characteristics of the sorbed organic C were also examined. Soil pH in the C horizon soil-bags steadily decreased (5.2 to 3.7) as the result of organic acid leaching. Nitrogen and S accumulation beneath the O horizons was strongly related to the accumulation of C whereas P was not. Phosphorus was weathered from the C horizon material, with lower soil pH and greater organic C leading to greater P loss. The intensity of organic acid leaching was examined as a possible control on the changes that were observed. These results have important land management implications relating to forest health that can only be obtained with long-term studies.

Key Words
Organic matter, spruce-fir, ratios.

Introduction
Soil formation is a complex process that varies with climate, relief, parent material, organisms, and time. Most soil genesis and weathering experiments are short-term and focus on addressing primarily climate, relief, parent material, or organism as a single factor. Long-term soil genesis experiments are rare and are designed to evaluate the factor of time. There is a need to apply experimental designs of long-term soil studies (Richter *et al.* 2007) to different ecosystems such as forests due to their crucial role in carbon sequestration and to maintain forest productivity.

In the early 1990s, we established a long-term soil experiment to better understand the dynamics of C, N, S, and P in nutrient poor Spodosols in central Maine, USA focusing on forest floor to mineral soil transfers. Little is known about the critical organic pools of these nutrients, particularly during long time scales. We took advantage of the existing experimental design at Howland for this study. We revisited the sites during the summer of 2009 and retrieved one set of bags (others had been collected in 1993, 1994, and 1997). Newly obtained samples were compared with original, archived samples for changes in pH and organic matter. Both natural weathering processes and anthropogenic impacts such as acidic deposition were likely to lead to changes in our soil-bags. Understanding how soils change during long time periods can have important land management implications relating to forest health. Our objectives were to: 1) examine soil formation and weathering in a spruce-fir forested Spodosol; and 2) better understand organic leaching from the forest floor to mineral horizons.

Methods
A study on organic matter quantity and quality begun in 1992 was utilized for this project. The study site was a commercial spruce-fir forested plot located at Howland, Maine. Previous work on organic matter quality had been conducted, as well as dissolved organic C leaching studies (Dai *et al.* 1996abc; Christ *et al.* 1997). These soils have thick organic horizons (10 to 25 cm) and well developed E horizons 2 to 5 cm thick. As part of the initial work in 1992, a long-term soils experiment was set up. Sixty soil-bags were constructed using C horizon material (loamy sand, 83% sand, 15% silt, 2% clay) from a large soil pit in the plot, and placed directly beneath the Oa horizon in groups of five at 12 locations (sampling was planned to occur five times). The soil-bags were constructed of 250-µm nylon mesh cloth sewn on three sides and stapled on the forth side (David *et al.* 1990). Additional bags were placed in the center of the B horizon. Another set of bags filled with acid washed sand were also installed at that time at the same locations.

We excavated a total of 36 soil-bags from the site in June of 2009, following 17 years of incubation (Figure 1). One C horizon and one sand bag were collected from each of the 12 incubation locations, as well as B horizon bags from 4 locations. All samples were immediately frozen and then freeze-dried for further analysis, and were compared with original, archived samples as well as samples collected after 1, 2, and 5 years of field exposure.

Figure 1. Spodosol soil pit showing excavated soil-bags.

For this paper, preliminary results from soil-bags containing C horizon materials were analyzed and compared to archived soil. The methods used to analyze the samples were the same as in Christ *et al.* (1997) and Dai *et al.* (1996abc).

Results

Soil-bags placed beneath the O horizon were enriched with C, N, and S, but depleted in P compared with the original material. P is tightly cycled in this forest, and so that the dissolved organic matter (DOM) leached from the O horizons was low in P. Mineral P was likely weathered from the soil-bags. Soil-bags buried deeper in the soil profile accumulated much less C, N, and S and had less P weathering compared to the soil-bags buried directly beneath the O horizons (Table 1). Organic matter deposited on the C horizon material was enriched in N, S, and P following the 17-year leaching period as there were much lower C/N, C/S, and C/P ratios in comparison with soil profile data.

Table 1. Horizon characteristics (1992) along with C horizon soil-bags incubated for 17 years.

		Total (mg/kg)						
	pH	C	N	S	P	C/N	C/S	C/P
Oa horizon	2.54	495,000	9,200	1,100	420	54	460	1,200
E horizon	3.24	6,000	290	290	80	21	21	76
2009 soil-bag C under Oa	3.75	4,100	106	30	200	39	140	21
Bhs horizon	4.24	45,400	1,550	520	350	29	87	130
2009 soil-bag C within Bhs	4.83	1,000	100	20	240	10	46	4
C horizon	5.17	2,000	150	180	300	13	11	7

Total N and S concentrations were positively correlated with total C concentrations (Figure 2a) whereas total P had an inverse pattern (Figure 2b). Phosphorus is a limiting nutrient in this spruce-fir system. Plants and microbes take up most of the available P in the O horizons (Christ *et al.* 1997) leaving less to be leached into the soil-bags buried directly underneath the O horizon. Natural weathering of P over the past 17 years did cause substantial loss from the C horizon soil-bags from the Oa location in the soil profile.

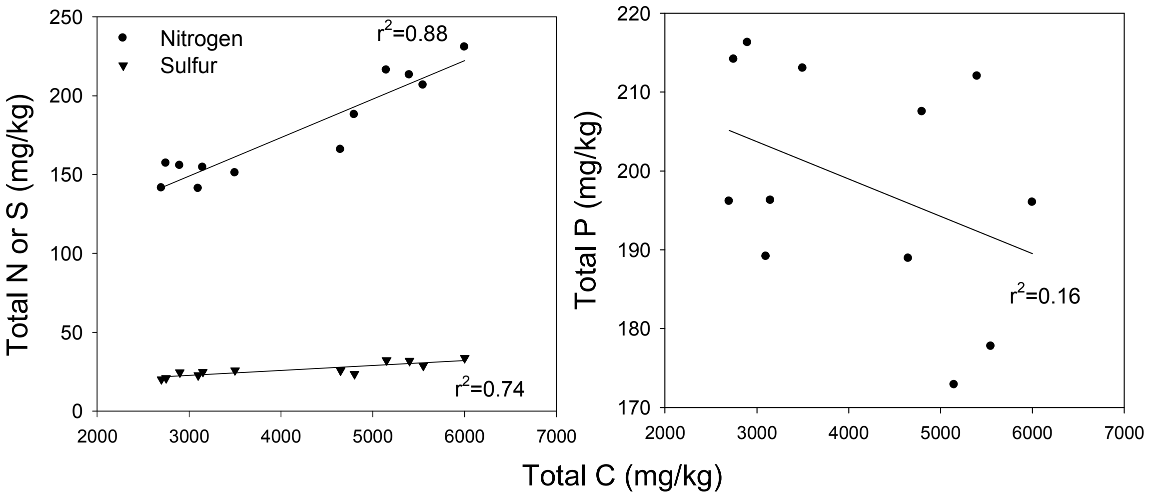

Figure 2. Relationships between total C and N or S and P of individual soil-bags collected in 2009. Linear regression r^2 values also shown.

The pH (0.01 M $CaCl_2$) of the soil-bags buried beneath the Oa horizon decreased from 5.30 to 3.75, with a more rapid decrease in years 1 to 5 (Figure 3a). Organic matter content (measured as loss-on-ignition) increased from an average of 0.55 to 1.2% (Figure 3b). For individual soil-bags incubated for 17 years, total C was strongly related to pH, demonstrating differential weathering and OM accumulation (Figure 4).

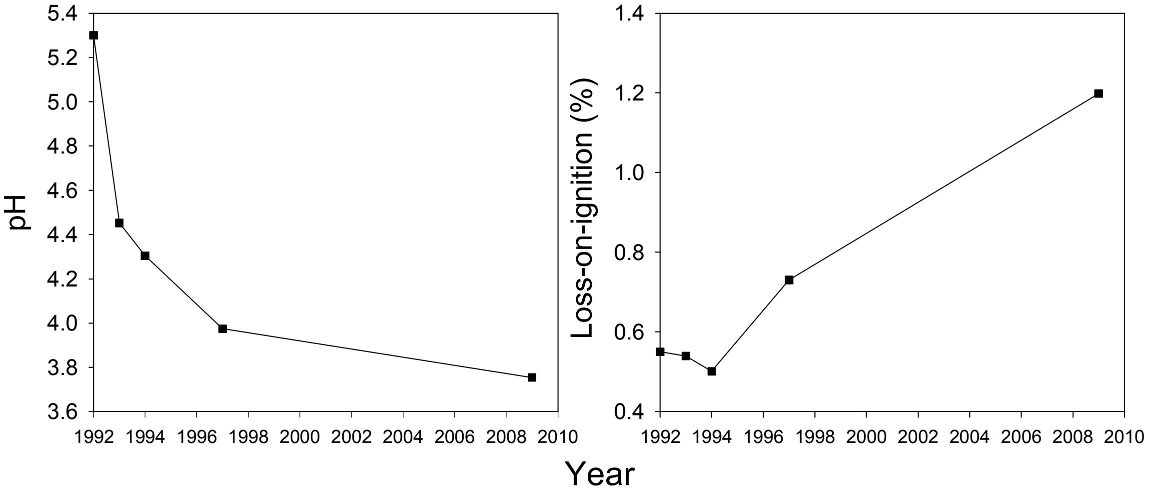

Figure 3. Changes in pH and LOI of C horizon soil-bags during 17 years beneath the Oa horizon.

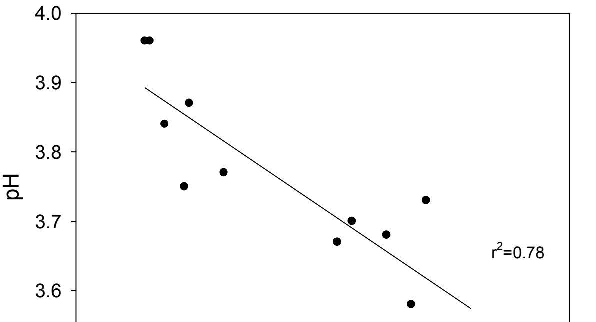

Figure 4. Relationship (linear regression r^2 shown) between total C and pH of individual soil-bags collected in 2009.

Conclusion

Soil pH in the soil-bags has steadily decreased as the result of organic acid leaching. Nitrogen and S accumulation beneath the Oa horizon was strongly related to the accumulation of C whereas P was not. Phosphorus was weathered from the C horizon material, with lower soil pH and higher total C leading to greater P loss. Further analysis from these unique soils should provide a better understanding of organic matter leaching in these soils.

References

Christ MJ, David MB, McHale PJ, McLaughlin JW, Mitchell MJ, Rustad LE, Fernandez IJ (1997) Microclimatic control of microbial C, N, and P pools in Spodosol Oa-horizons. *Canadian Journal of Forest Research* **27**, 1914-1921.

Dai KH, David MB, Vance GF (1996a) Characterization of solid and dissolved carbon in a spruce-fir Spodosol. *Biogeochemistry* **35**, 339-365.

Dai KH, David MB, Vance GF, Krzyszowska AJ (1996b) Characterization of phosphorus in a spruce-fir Spodosol by phosphorus-31 nuclear magnetic resonance spectroscopy. *Soil Science Society of America Journal* **60**, 1943-1950.

Dai KH, David MB, Vance GF, McLaughlin JW, Fernandez IJ(1996c) Acidity characteristics of soluble organic substances in spruce-fir forest floor leachates. *Soil Science* **161**, 694-704.

David MB, Fuller RD, Fernandez IJ, Mitchell MJ, Rustad LE, Vance GF, Stam AC, Nodvin SC (1990) Spodosol variability and assessment of response to acidic deposition. *Soil Science Society of America Journal* **54**, 541-548.

Richter DD, Hofmockel M, Callaham MA, Powlson DS, Smith P (2007) Long-term soil experiments: keys to managing Earth's rapidly changing ecosystems. *Soil Science Society of America Journal* **71**, 266-279.

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Micromorphological and chemical characteristics of placic and ortstein horizons in subtropical subalpine forests

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Abstract
Pedons with a placic or ortstein horizon are commonly occurred in the subalpine and alpine forests in Taiwan. We selected a representative pedon with well-developed placic horizon in subalpine forests in northeastern Taiwan and another with a well-developed ortstein horizon in subalpine forests in central Taiwan to compare the differences between these two horizons. Micromorphological observations indicated that the placic horizon was characterized by vughy microstructure and was composed of iron oxides, whereas ortstein horizon was characterized by granular and bridge microstructures between quartz grains. Analytical results of cementing materials between skeleton grains in these two horizons by using energy dispersive spectrometry (EDS) further indicated that Fe, O and C were predominant elements in the placic horizon, whereas Al, Si and C were major elements of the cementing materials in the ortstein horizon. The elemental mapping determining by electron probe micro-analyses (EPMA) also indicated that organically complexed-Al was the dominant material, which was present between soil aggregates and coated on quartz grains in the ortstein horizon as compared with those of the placic horizon. Chemical analytical results showed that pedogenic Fe (Fe_d) was the dominant Fe fraction in both placic and ortstein horizons; however, the Fe_d contents were much higher in the placic horizon than in the ortstein horizon. Dominant Al fractions were different between the two horizons, organically complexed-Al (Al_p) was predominant in the ortstein horizon, and pedogenic Al (Al_d) was dominant in the placic horizon. We concluded that different formation mechanisms occurred between these two horizons; the placic horizon was related to redox processes, and the ortstein horizons related to podzolization.

Key Words
Energy dispersive spectrometry (EDS), micromorphology, placic horizon, ortstein horizon.

Introduction
Hardened soil layers, placic or ortstein horizons common occur in the subalpine or alpine forest soils, and their genesis is not fully understood, especially in subtropical or tropical forest ecosystems in Taiwan. The definition of the placic horizon in US soil taxonomy is a thin (< 25 mm), black to dark reddish pan which cemented by iron (or iron and manganese) and organic matter (Soil Survey Staff 1975). The ortstein horizon is commonly an illuvial hardened horizon such as Bh and Bs horizons in Spodosol or Podzol, and these horizons are at least 25 mm thick (Soil Survey Staff 1975). Both of these horizons are severely influence the drainage and plant growth of forest ecosystems and their management. Several hypotheses have been proposed for the formation of the placic horizon, including translocation and precipitation of organic Fe complexes (Conry *et al.* 1996; Clayden *et al.* 1990), and mobilization of reduced Fe in the upper parts and then oxidation in lower soil horizons (Lapen and Wang 1999; Pinheiro *et al.* 2004). With regard to the formation of the ortstein horizon; the translocation and precipitation of organic Fe and/or Al complexes is a dominant mechanism (Lee *et al.* 1988; Lapen and Wang 1999).

Taiwan is located at the tropical and subtropical climatic regions, and more than 70% of the lands is mountain covered by various forests. In the subalpine and alpine forest ecosystems, clear illuvial processes and strong chemical weathering prevail in these soils due to the great amount of annual rainfall (≥ 3000 mm). Podzolic soils and soils with placic horizon have been found by Li *et al.* (1998), Hseu *et al.* (1999) and Wu and Chen (2005) in the subalpine cloud forests of northern Taiwan. However, clearly comparison of genesis between these soils is rare. The objectives of this study are to combine micromorphological observations, EDS analyses, electron probe micro-analyses (EPMA) and bulk soil chemical extraction to determine the geochemical characteristics of the placic and ortstein horizons and to deduce the differences of the formation processes between the placic and ortstein horizons in the subtropical subalpine ecosystem.

Methods

Environmental setting and soil characteristics

The TPS site (around 24°32’ N, 121° 56’ E) is located at Mt. Taiping with altitude of 2200 m, where mean annual air temperature is 10 °C and total annual rainfall is 3200 mm, in northeastern Taiwan (Figure 1). The parent materials are comprised shale and slate (Ho 1986). Cypress forest of Taiwan red cypress (*Chamaecyparis formosensis* Matsum), Taiwan Chinese fir (*Taiwania cryptomerioides* Hay.) and Willow fir (*Cryptomeria japonica* Hassk.) are dominant vegetation. In addition, the placic horizon was common characteristics within the soils at this site (Wu and Chen 2005). Based on previous investigation studies (Hseu *et al.* 1999; Wu and Chen 2005), we selected a representative pedon with well-developed placic horizons on the summit position, and it was classified as Typic Hapludults with placic horizon based on US Soil Taxonomy (Soil Survey Staff 2006). The SLS site is located at Mt. Fenghuang with altitude of 1700 m (around 23°38’ N, 120° 47’ E), where mean annual air temperature is 16 ^{o}C and total annual rainfall is 2600 mm, in central Taiwan. The parent material of this site is mainly composed of sandstone. Based on pre-investigation of soil distribution, the soils with distinct eluvial and ortstein horizons were commonly found on the summit position at this area. Accordingly, we selected a representative pedon with well-developed ortstein horizons on the summit position, and it was classified as Typic Haplorthod based on US Soil Taxonomy.

Soil analyses

Soil samples were collected from each horizon of the two pedons for physical and chemical analysis. Soil analyses included pH, total organic carbon (TOC) contents, cation exchange capacity (CEC), dithionite-citrate-bicarbonate (DCB) extracted Fe and Al (Fe_d and Al_d), ammonium oxalate extracted Fe and Al at pH 3.0 (Fe_o and Al_o), and sodium pyrophosphate (pH 10) extracted Fe and Al (Fe_p and Al_p).Total contents of major metal elements in soils were determined by X-ray fluorescence spectrometry (XRF) (RIGAKU, ZSX Primus II, Japan) with Rh target and a beam voltage of 20 kV. Analytical quality of the XRF measurements was controlled by analyzing standard reference material (NIST-2709) certified by National Institute of Standards and Technology (NIST), USA.

Soil micromorphology

Kubiena boxes were used to collect undisturbed soil blocks in the field for making thin section. Vertically oriented thin sections which 5 × 8 cm and with a thickness of 30 μm were prepared by Spectrum Petrographics, Inc., Winston, Oregon, USA. The thin sections were observed for all soil horizons using a polarized microscope (AFX-Ⅱ Type, Nikon Precision Instruments, Belmont, CA). Meanwhile, we also made the polished slides for soil placic horizon. The selected samples were mounted in cold-mounting epoxy resin (EpoFix, Struers Co.) with 1-inch diameter mold at the room temperature for over night. The mounted samples were ground by SiC and then polished by alumina paste (up to 0.3 μm) until surface exposed well. Each polished sample was initially observed by an optical microscope with the reflection light, and then, a scanning electron microscope (SEM; JEOL JSM-6360LV) was used to observe micro-scale texture. Back-scattered electron image, which represents mean atomic abundance by contrast in back and white image, were observed from the surface of the polished section. Identification of mineral phases were made by an energy dispersive spectrometer (EDS; Oxford Instruments Ltd., INCA-300) which equipped with SEM, under the beam conditions of 15 kilovolt (kV), and 180 picoampere (pA) for the acceleration voltage, and beam current, respectively, in the vacuum condition of 25 Pascal (Pa) without carbon coating.

Results

The placic horizon

The placic horizon of Typic Hapludults at the TPS site exhibited hard structure and undifferentiated fabric with small voids and plane channels, which reflected dense structures of the placic horizon (Figure 2a and b). The above-mentioned micomorphological features are commonly observed in thin section. The placic horizon was characterized by high contents of Fe_d and Fe_t ($\geq$ 330 g/kg), low contents of organically complexed-Fe ($\leq$ 70 g/kg) and Al ($\leq$ 5 g/kg), and low ratio of Fe_p/Fe_d ($\leq$ 0.25) (Table 1). Additionally, high content of Fe oxides and Fe/Al ratio of the cementing materials between skeleton grains were estimated by EDS (Table 2). The results indicated that inorganic Fe was dominantly distributed in the soil matrix and cementing materials between quartz grains (Figure 3a, b, c and d), which also indicated that redox processes were dominant pedogenic processes in the placic horizon.

The ortstein horizon

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The ortstein horizon of Typic Haplorthods at the SLS site is characterized by bridge and granular microstructures, and with high proportion of large voids such as chamber and channels (Figure 2c and d). The above-mentioned micomorphological features are commonly observed in the thin sections. The ortstein horizon also has much lower contents of Fe_d and Fe_t (≤ 80 g/kg), compared to those of placic horizon, whereas slightly higher contents of organically complexed-Al (about 10 g/kg) and high ratio of Al_p/Al_d (≥ 0.54) were present in the ortstein horizon (Table 1). Meanwhile, EDS results also showed that relatively low Fe/Al ratio in the cementing materials between soil aggregates and coatings on the quartz grains (Table 2). We conclude that aluminosilicates and pedogenic Fe were distributed in the soil matrix, however, the cementing materials between soil aggregates and coatings on the quartz grains of the ortstein horizon were composed of organically complexed-Al, which were further supported by the elemental mapping of EPMA (Figure 3e, f, g and h). The formation of the ortstein horizon is considered as a process related to podzolization.

Table 1. DCB-, oxalate- and pyrophosphate-extractable Fe and Al in two pedons.

Pedon	Horizon	Depth	Fe_d	Al_d	Fe_o	Al_o	Fe_p	Al_p	Fe_t	Fe_p/Fe_d	Al_p/Al_d	Fe_p/Fe_o	Al_p/Al_o	Al_o +1/2Fe_o
		(cm)	(---------------------------g/kg-----------------------)											
TPS	O	5-0	3.73	1.16	2.02	1.06	0.85	0.81	4.37	0.23	-	-	-	-
	A	0-7	5.13	2.11	2.86	1.92	2.52	1.65	5.94	0.49	0.78	0.86	0.88	0.34
	E	7-21	0.38	2.23	0.18	3.15	0.17	2.43	3.79	0.45	1.09	0.77	0.94	0.32
	Bsm	21-22.7	327	10.2	174	4.73	71.3	4.49	331	0.22	0.44	0.95	0.41	9.17
	Bt1	22.7-45	61.0	9.24	18.0	4.39	38.1	8.27	62.0	0.62	0.90	1.88	2.12	1.34
SLS	O	13-0	-	-	-	-	-	-	-	-	-	-	-	-
	A	0-4	3.49	1.08	0.85	0.74	1.00	0.95	6.63	0.29	0.88	1.28	1.18	0.12
	2E	4-11	4.16	0.67	0.95	0.53	0.93	0.44	5.39	0.22	0.66	0.83	0.98	0.10
	2Bh	11-32	79.3	17.8	12.0	5.32	22.3	9.59	63.8	0.28	0.54	1.80	1.86	1.13
	2Bs	32-47	40.6	7.21	2.68	2.20	11.5	4.17	45.2	0.28	0.58	1.90	4.29	0.35
	2BC	>47	28.4	9.99	1.50	2.12	1.71	2.46	-	0.06	0.25	1.16	1.14	0.29

Table 2. Elemental composition of the cementing materials in the placic and ortstein horizon.

	Placic (Bsm) value (%)	standard deviation	Ortstein (2Bh) value (%)	standard deviation
SiO_2	19.6	1.54	21.5	6.07
Al_2O_3	10.2	0.53	15.8	3.07
FeO	48.3	4.56	8.62	2.57
K_2O	1.15	0.10	1.02	1.18
MgO	-	-	0.33	0.20
TiO_2	-	-	0.70	1.28
Total	79.2		48.0	
Sample number	7		12	
SiO_2/Al_2O_3	1.92		1.36	
FeO/Al_2O_3	4.74		0.55	

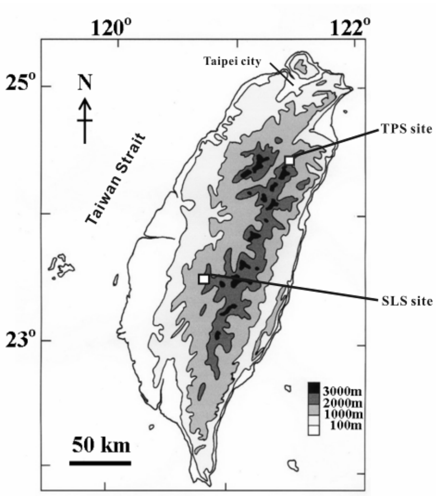

Figure 1. The studied sites in Taiwan.

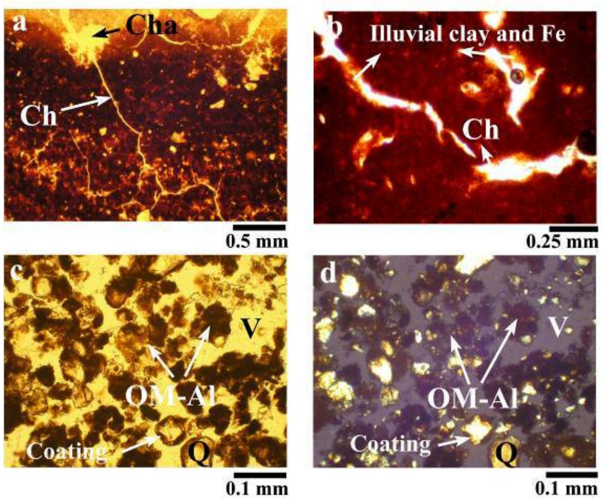

Figure 2. The micromorphological photos of the placic horizon (a: with a plane polarized light (PPL); b: with a PPL) and ortstein horizon (c: with a PPL; d: with a cross polarized light (XPL)). (OM-Al: organically complexed-Al; Cha: chamber; Ch: channel; V: void; Q: quartz).

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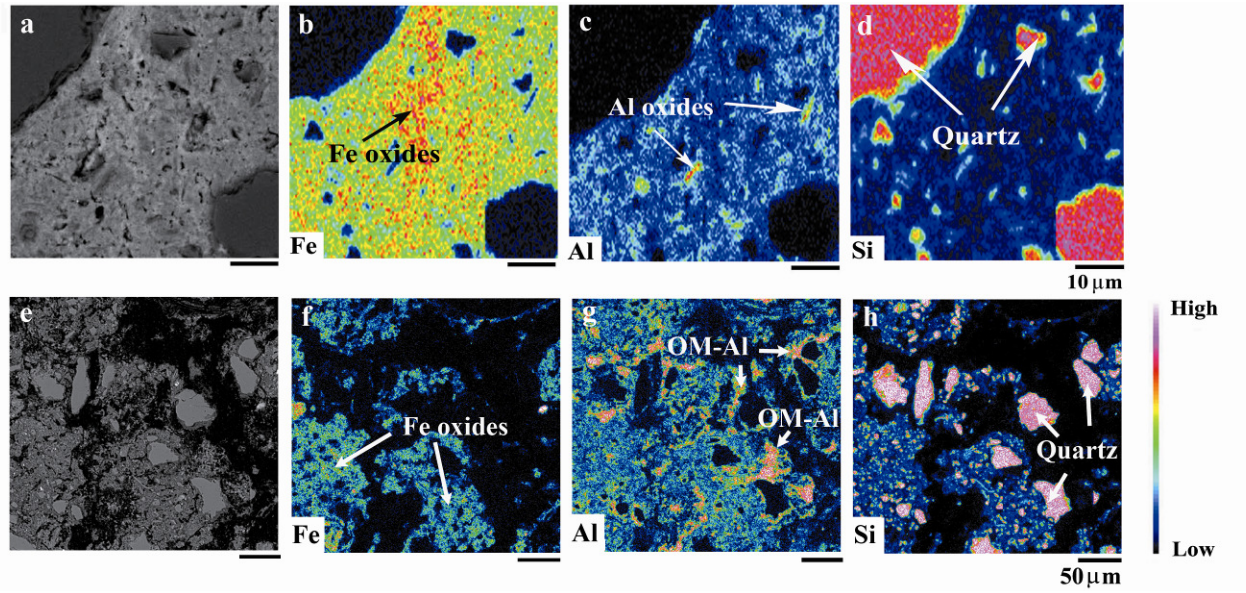

Figure 3. The spatial distribution of Fe, Al and Si in the placic horizon (a, b, c and d) and ortstein horizon (e, f, g, and h); a and e are back electron image of the placic and ortstein horizon, respectively. (OM-Al: organically complexed-Al).

Conclusions

Significant differences were present between the placic horizon and ortstein horizon; denser microstructure and less porosity were found in the placic horizon as compared to the ortstein horizon. Predominant pedogenic Fe were found in the placic horizon and predominant organically complexed-Al was found in the ortstein horizon, which indicated that different formation processes occurred between the two horizons. The formation of placic horizon reflects the redox process, whereas the ortstein horizon is due to the podzolization. Additionally, we conclude that poor drainage of clayey pedons located in TPS subalpine forests led to saturated and reduced conditions in the surface soils; textural difference and pH gradient enhanced the accumulation and oxidization of Fe above the B horizon and formed the placic horizon rather than an ortstein horizon. Texture is a critical factor controlly the formation of placic and ortstein horizons in the humid subalpine forests in Taiwan.

References

Clayden B, Daly BK, Lee R, Mew G (1990) The nature, occurrence, and genesis of placic horizons. In 'Proceedings of Fifth International Soil Correlation Meeting' (Ed JM Kimble) pp. 88-104. (USDA-SCS, Lincoln)

Conry MJ, de Coninck F, Stoops G (1996) The properties, genesis and significance of a man-made iron pan podzol near Castletownbere, Ireland. *European Journal of Soil Science* **47**, 279-284.

Ho CS (1988) 'An introduction to the geology of Taiwan: explanatory text of the geologic map of Taiwan'. 2nd edition. (Central Geologic Survey: Taiwan)

Hseu ZY, Chen ZS, Wu ZD (1999) Characterization of placic horizons in two subalpine Inceptisols. *Soil Science Society America Journal* **63,** 941-947.

Lapen DR, Wang C (1999) Placic and Ortstein horizon genesis and peatland development, southeastern Newfoundland. *Soil Science Society America Journal* **63**, 1472-1482.

Li SY, Chen ZS, Liu JC (1998) Subalpine loamy Spodosols in Taiwan: characteristics, micromorphology, and genesis. *Soil Science Society America Journal* **62**, 710-716.

Pinheiro J, Tejidor Salguero M, Rodriguez A (2004) Genesis of placic horizons in Andisols from Terceira Island Azores-Portugal. *Catena* **56**, 85-94.

Soil Survey Staff (1975) 'Soil Taxonomy'. USDA-NRCS Agricultural Handbook No. 436, (U.S. Government Printing Office: Washington, D.C.)

Soil Survey Staff (2006) 'Keys to Soil Taxonomy'. USDA-NRCS, Agricultural Handbook No. 436, 10th editoin. (U.S. Government Printing Office: Washington, DC)

Wu SP, Chen ZS (2005) Characteristics and genesis of Inceptisols with placic horizons in the subalpine forest soils of Taiwan. *Geoderma* **125**, 331–341.

Mine soil suitability for native forests in the USA

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Abstract
Northern red oak is a valuable, native commercial species in large areas of the eastern USA. Little is known about preferred site and soil conditions for this species on mined land. The purpose of our field study was to test red oak survival and growth rates on a variety of topsoil substitutes. The site was mined in 1979 and reclaimed in 1980. In 1981, field plots were constructed with different topsoil substitutes spoil mixes and pitch x loblolly pines were planted in 1983. In 2001 the pines were removed and replaced with red oaks in the winter of 2001-2002. Four replicate plots of five different mine spoil mixes were planted with nine red oak seedlings each. Tree survival, height and diameter were measured each year for five years. Survival and growth was best on topsoil substitutes consisting of a mix of sandstone and siltstone. Trees survived and grew poorly on plots constructed from either pure sandstone or siltstone. Reasons for the poor oak performance on the high sandstone plots were related to lower pH and available Ca levels. Poor oak performance on the pure siltstone plots was likely related to higher rock fragment and lower bulk water holding content.

Key Words
Reclamation, coal mined land, forest management, soil quality, mine soils.

Introduction
The Appalachian coalfields region is heavily forested with native temperate hardwoods. The forest has been a major economic resource since the region was settled by Europeans more than 200 years ago. In addition to wood products, the forest provides ecosystem services including watershed protection, water quality, carbon sequestration, wildlife habitat, and habitat for many understory plants and animals used for food and sustenance by local communities (Braun 1950). Since the implementation of the Surface Mining Control and Reclamation Act (SMCRA) in 1978, most reclaimed mines were re-vegetated with grasses and other herbaceous plants. Because there is no significant livestock industry in the steeper mountains, and because these new grasslands are usually remote, at high elevation, and with little water, the grassland created on mined land is usually abandoned to become low-value scrubland. Restoring adequate mine soil quality for trees using suitable topsoil substitutes has been an on-going issue (Bussler *et al.* 1984, Rodrigue and Burger 2004). In 1983 we planted pines in different mixtures of sandstone and siltstone overburdens on a study site in Wise County, Virginia. The site had been a native hardwood forest on steep terrain prior to mining, and after mining it was relatively level and was surrounded by a variety of post-mining land uses ranging from pasture to pine plantations. Pines grew best in mine soils with a high proportion of lower pH sandstone spoil despite overall lower fertility compared to that in the siltstone spoil (Torbert *et al.* 1990). This led to a recommendation that weathered, slightly acid sandstone spoils be used for topsoil substitutes for forestry post-mining land uses. However, with increasing interest in commercially valuable native hardwoods, we revisited the issue to determine which mine soil types are most suitable for these more demanding hardwood species.

The objective of this research was to determine the suitability of different topsoil substitutes for northern red oak (*Quercus rubra* L.) after removing pines that had been planted in the same area immediately after reclamation and had been in place for 19 years. The topsoil substitutes were made up of different proportions of sandstone and siltstone overburden. Red oak was chosen as an indicator species because of its commercial value, its sensitivity to mine soil conditions, and the fact that it shares many resource requirements with other native hardwood species (Johnson *et al.* 2002).

Methods
The study site is located in Wise County, Virginia. The study plots were constructed during the winter of 1981 on a previously mined flat bench. The area around the site was mined in 1983, which left the surrounding terrain relatively flat. The treatment plots consisted of four replications of five overburden mixes that included pure sandstone (SS), pure siltstone (SiS), 2:1 SS:SiS, 1:1 SS:SiS, and 1:2 SS:SiS arranged in a

randomized complete block design. The spoils were mixed in the required ratios and placed in the centers of adjacent 3.05 x 6.1 x 1.25 m deep plots. In the spring of 1983, each plot was planted with nine containerized 1-0 pitch x loblolly pine hybrid (*Pinus rigida* Mill. x *Pinus taeda* L.) seedlings. Tree survival, height, and ground line diameter of the stem were measured in the fall of each year for the 5-yr study period. The results of the study were reported by Torbert *et al.* (1990).

Trees were removed in 2001, and in 2002 each of the 20 plots was replanted with nine 2-0 northern red oak seedlings. Survival, height, and ground line diameter of the trees were measured in the fall each year for five years. At the end of the fifth field growing season for both the pines (1987 and the oaks (2006), two 1-kg soil samples were taken from each plot and combined for a single composite sample. Soil physical and chemical properties were determined using standard methods. Data were summarized and analyzed using ANOVA and regression statistics (SAS 2004).

Results and Discussion

Pine growth was greatly affected by overburden type. Tree volume in the study plots decreased proportionately with added siltstone (Torbert *et al.* 1990) (Figure 1). Torbert and co-workers attributed the decrease in tree production to a combination of physical and chemical properties, namely coarse fragment content, pH, and higher initial soluble salt content, all of which increased with increasing amounts of siltstone (Figure 2). Pine growth was inversely proportional to soluble salt content; growth decreased linearly as salt content increased (Figure 2). Soluble salt content ranged from 1280 to 4160 mg/kg 1987 with increasing amounts of siltstone in the first five years of the experiment. In contrast to the pines, the northern red oaks grew best in topsoil substitutes consisting of 1:1 SS:SiS and 1:2 SS:SiS (Figure 1, Table 1). Average tree height on the 1:2 SS:SiS sandstone:siltstone mixture was greater than the average tree height on either of the pure rock types. The trends in ground line diameter, tree volume index (TVI = diameter^2 x height), and plot volume index (TVI x % survival / 100) were the same as that for tree height (Table 1). Tree survival was very close to 70% at age 5 for all treatments except for the pure sandstone, which was only 25%. Seventy percent survival is common and considered good for mixed native hardwoods planted in good mine soils.

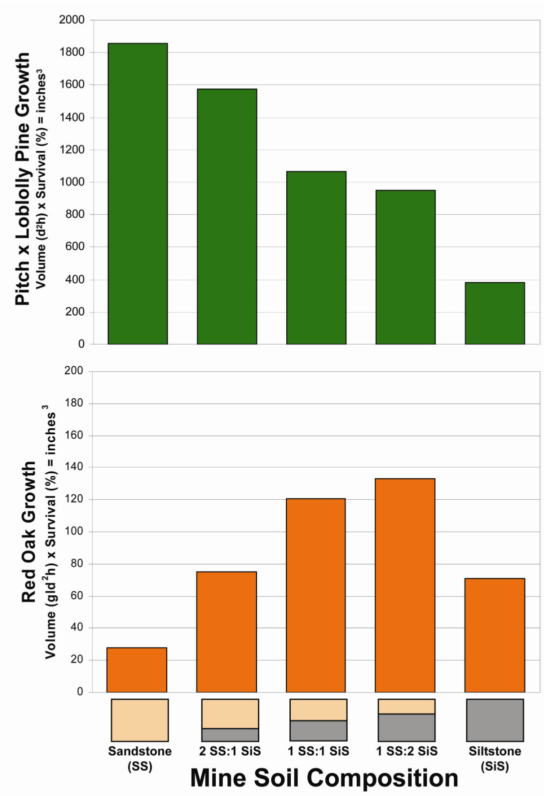

Figure 1. Pine and red oak production in topsoil substitutes consisting of different amounts of sandstone and siltstone. Tree growth is shown as an estimate of biomass volume x survival (ground line d^{2}h x % survival/100) (Pine data from Torbert *et al.* 1990).

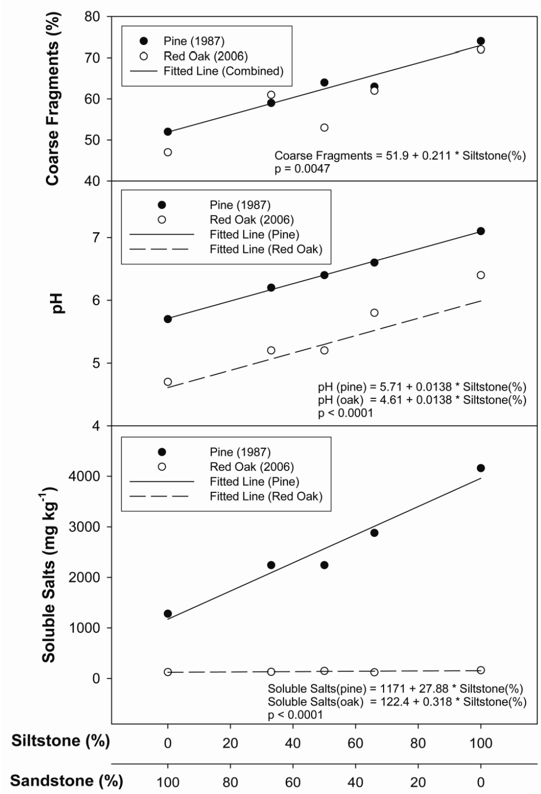

Figure 2. Coarse fragment content, pH, and soluble salt content for increasing amounts of siltstone versus sandstone used as a topsoil substitute for growing pitch x loblolly pines (1983-1987) (Torbert *et al.* 1990) followed by northern red oaks (2002-2006).

By 2002, when the red oaks were planted, the mine soils had been in place and weathering for 20 years. Furthermore, the mine soils had been exposed to the influences of a pine cover for 19 years. When the soils were sampled in 2006, they had been in place for 25 years. Therefore, differences in soil properties between sampling periods (1987 and 2006) are largely a function of parent material (sandstone versus siltstone), but would also be a function of time and vegetation (pines and northern red oak).

Total N and C, averaging 0.2 and 3%, respectively, were comparable to levels found in non-mined, managed forest soils of the southeastern United States (Fisher and Binkley 2000) (Table 3). The only soil property that appeared correlated with tree growth was the soil CEC corrected for fine earth content (Table 2). The CEC was lowest for the pure rock types and highest for the mixtures, which corresponded to red oak growth. An overall CEC of only 2.0 $cmol^+$ /kg is an indication of potentially low soil fertility by agricultural standards, but this level is common in moderately to strongly acid native forest soils (Fisher and Binkley 2000). Of the soil properties measured for this study, low soil P and high coarse fragment content are possible factors contributing to the poor red oak growth on the pure siltstone (Showalter *et al.* 2005).

Based on these data, the red oaks survived and grew poorly on the sandstone mine soil. This soil had the highest levels of available N and P, which were comparable to or higher than those found on an adjacent sandstone study site growing healthy 15-year-old sugar maples (Burger and Salzberg, in press). However, the sandstone pH in this study (4.7) was one unit lower than that on the sugar maple site (5.7). A combination of strong acidity and the lowest levels of exchangeable bases were possible causes of the poor performance on sandstone.

Table 1. Survival and growth of planted northern red oaks growing on sandstone and siltstone topsoil substitutes.

	Survival		Growth (age 5)			
	Year 1	Year 5	Diameter[1]	Height	TVI[2]	PVI[3]
	(-------- % --------)		(cm)	(cm)	(cm^3)	
Sandstone	64	25[b]	2.8	116[b]	1822	456
2:1 SS:SiS	78	69[a]	3.1	146[ab]	1777	1226
1:1 SS:SiS	75	69[a]	3.1	151[ab]	2869	1980
1:2 SS:SiS	83	72[a]	3.7	174[a]	3026	3179
Siltstone	75	69[a]	3.0	122[b]	1696	1170

[1]Diameter at ground line.
[2]Mean Tree Volume Index = (ground line diameter)^2 x (height)
[3]Plot Volume Index = (TVI)(% survival) / 100

Table 2. Selected physical and chemical properties for sandstone and siltstone topsoil substitutes under red oak.

Mine Soil	Fine Earth	pH	Soluble Salts	Olsen[1] P	Inorganic[1] N (KCl)	CEC[2] (x FE)
	(%)		(ppm)	------- kg/ha -------		($cmol^+$ /kg)
Sandstone	53[a]	4.7[d]	125	24.5	35.0	1.85
2:1 SS:SiS	39[b]	5.2[c]	131	11.5	27.1	2.02
1:1 SS:SiS	47[ab]	5.2[c]	150	16.7	35.1	2.26
1:2 SS:SiS	38[bc]	5.9[b]	122	9.0	18.6	2.20
Siltstone	28[c]	6.4[a]	163	7.7	13.1	1.60

[1]kg/ha values based on D_b = 1.3 g/cm^3 and soil layer = 0-20 cm (Olsen and Sommers 1982).
[2]CEC x fine earth (FE) fraction

Table 3. Total nitrogen and carbon and exchangeable cations for sandstone and siltstone topsoil substitutes under red oak.

Mine Soil	Total N[1]		Total C[1]		Exchangeable Cations[2]			
					Ca	K	Mg	Na
	(%)	(kg/ha)	(%)	(Mg/ha)	---------- ($cmol^+$ /kg) ----------			
Sandstone	0.16	2204	2.91	40.0	2.43	0.05[b]	1.01[d]	0.05
2:1 SS:SiS	0.18	1920	3.55	37.6	3.11	0.07[a]	1.98[bc]	0.06
1:1 SS:SiS	0.19	2368	3.50	43.7	2.82	0.08[a]	1.88[c]	0.07
1:2 SS:SiS	0.17	1713	3.32	32.2	3.37	0.08[a]	2.29[b]	0.05
Siltstone	0.22	1519	4.34	30.2	2.76	0.08[a]	2.88[a]	0.05

[1]kg/ha values based on D_b = 1.3 g/cm^3 and soil layer = 0-20 cm.
[2]Ammonium acetate extracts.

Conclusion

In contrast to the pitch x loblolly pines, which preceded the northern red oaks on the same study plots, red oaks clearly grew best in a mix of sandstone and siltstone. They survived well on all the mine soils except pure sandstone, but grew poorly on both pure sandstone and pure siltstone. This difference in growth between the two species may show a species preference for different mine soils; however, the reason for this preference could not be attributed to a single mine soil property. Northern red oaks, along with most other native hardwoods, are known to have a higher base nutrient requirement than pines, which may explain their better performance in the mixtures of the two rock types, while low soil P, high coarse fragment content, and low water availability may have slowed their growth in the pure siltstone. In any case, these results show that trees respond very differently to different mine soils, and they show that mine soils suitable for tree survival and growth should be used to restore forest productivity.

Acknowledgments

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References

Braun EL (1950) ‘Deciduous forests of Eastern North America.’ (The Blakiston Co.: Garden City, New York)

Burger JA, Salzberg A (2009) Sugar maple response to weed control, liming and fertilization on a reclaimed mine soil in southwestern Virginia. *Northern Journal of Applied Forestry* (in press).

Bussler BH, Byrnes WR, Pope PE, Chaney WR (1984) Properties of minesoil reclaimed for forest use. *Soil Science Society of America Journal* **48,** 178-184.

Fisher RF, Binkley D (2000) ‘Ecology and management of forest soils.’ (John Wiley & Sons: New York).

Johnson PS, Shifley SR, Rodgers R (2002) ‘The ecology and silviculture of oaks.’ (CABI Publishing: New York).

Olsen SR, Sommers LE (1982) Phosphorus. In ‘Methods of soil analysis, Pt. 2. Chemical and microbial properties.’ (Eds AL Page *et al.*) pp. 403-430. (American Society of Agronomy: Madison, WI).

Rodrigue JA, Burger JA (2004) Forest soil productivity of mined land in the midwestern and eastern coalfield regions. *Soil Science Society of America Journal* **68,** 1-11.

SAS Institute (2004) SAS System for Windows V8. (SAS Institute Inc.: Cary, NC).

Showalter JM, Burger JA, Zipper CE, Galbraith JM (2005) Influence of physical, chemical, and biological mine soil properties on white oak seedling growth. In ‘Proceedings of the 22nd Annual Meeting, American Society of Mining and Reclamation, Breckinridge, CO.’ (Ed RI Barnhisel) pp. 1029-1041 (ASMR: Lexington, KY)

Torbert JL, Burger JA, Daniels WL (1990) Pine growth variation associated with overburden rock type on a reclaimed surface mine in Virginia. *Journal of Environmental Quality* **19,** 88-92.

Monitoring scheme for examining carbon–water coupling in a forested watershed

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Abstract
Management of carbon and water in landscapes is one of the key issues of our time due to increased carbon emission and its associations with climate change. Sequestration of carbon in terrestrial ecosystems is proposed to overcome these challenges; however countries such as Australia where water is a limited resource are facing difficulties in providing water for carbon sequestration. Therefore it is important to understand the scale dependency of carbon and water and their coupling in ecosystems. The present study is the starting point of a series of experiments on carbon and water coupling in an ecosystem where sampling variance at four spatial scales was tested. A balanced nested sampling design with nine main stations, and 72 sampling sites at four spatial scales (5, 30, 100 and 400m) was established in a first order *Eucalyptus* forest catchment and soil carbon and clay variation were estimated. The dominant spatial scales in terms of variation were 5m and 400m for both clay and carbon, each comprising about 40% of the variation. However, at the 30m and 100m scales, 5-9% variations were observed suggesting the possibility for increasing the block size for soil carbon accounting.

Key Words
Nested sampling design, spatial scales, clay content, soil carbon, Eucalyptus forest catchment.

Introduction
In tackling increased carbon emission and its associated climate change, increasing attention is being given to sequestration of carbon in terrestrial ecosystems. Carbon, nitrogen and water processes are cyclic and strongly interrelated; therefore one cycle cannot be managed or disturbed without affecting the other. In order to increase carbon sequestration in ecosystems, water needs to be provided, however, countries such as Australia where water is a limited resource are facing challenges.
Carbon and water processes and their coupling have been studied extensively in the past; however, the focus has generally been at one spatial scale. A series of studies by M. Lark in recent times (Lark 2005; Corstanje & Lark 2008) has explored methods to examine scale dependency in the variation of individual properties, and their co-variation with other properties. In this assessment, we adopt one approach, the nested sampling designs first proposed by Youden and Mehlich (1937), where the data is analysed in the form of a random-effects nested ANOVA, except the nested scales are associated with distances in space, rather than regions. Lark (2005) extended the approach to enable an analysis of covariance for both balanced and unbalanced designs, allowing the correlations between different variables at different scales to be explored.
In terms of carbon and water, this scale dependency is important to understand as it has implications for how we manage carbon and water at different scales, depending on the strength and type of relationship. For example, the dilemma we face is that some studies have stated that storing more carbon via trees in landscapes resulting less water being available for the environment (Jackson *et al.* 2005). This if true would have dire consequences for the potential of storing carbon in Australia's dry landscapes. However, the study was based on catchment aggregated data so is limited to one scale.
In this paper, we describe the monitoring design, initial results and their implications, and future work.

Methods
Study Area
The study was conducted within a first-order forested catchment of Wollondilly River at Arthursleigh (34°33'49"S and 150°04'58"E) near Marulan, in the Southern Highlands of New South Wales, Australia. The region has a temperate climate (based on the Köppen classification) with mean annual precipitation of 800mm and mean annual temperature around 19.2°C (Bureau of Meteorology 2010). The study area is approximately 175 ha.

There has been no detailed soil survey performed in the area, however, the soil has been identified as Tenosols in the present survey. Soils have developed over sedimentary rocks, with a sandy texture consisting of 75-80% of sand. The soil depths range between 0.3 and 0.7m while the density of the vegetation is relatively low. The tree stratum of the area is mainly formed by Eucalyptus species, which are considered a part of the remaining virgin forests of Australia. Scattered shrub vegetation is also present in the area, however, a quite distinct range of heights is observed among the species, namely 10–15m for Eucalyptus and 0.50–1.0m for others. Coarse woody debris and fine litter materials are in abundance in the area.

Monitoring design, soil sampling and statistical analysis

The experiment was conducted as a balanced nested design (Youden and Mehlich 1937) with nine main stations. Each station consisted of eight sampling locations covering four spatial scales, i.e. 5m, 30m, 100m and 400m (Figure 1).

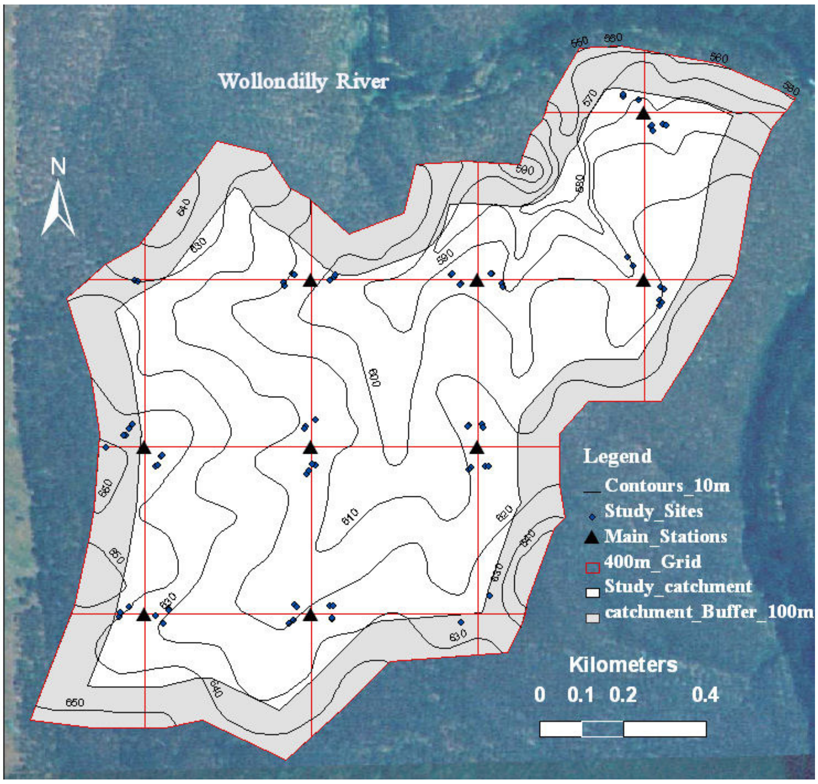

Figure 1. Main stations with study sites at Arthursleigh (©Contour Map -NSW Dept of Lands)

Statistical analysis was performed in the form of a random-effect nested ANOVA, where nested scales are associated with distances in space. To quantify the variance at each scale (σ^2_{5m}, σ^2_{30m}, σ^2_{400m} etc.), the following variance component model is used (Eqn. 1).

$$\begin{aligned}
&\sigma^2_{5m},\\
&\sigma^2_{5m} + \sigma^2_{30m}\\
&\sigma^2_{5m} + \sigma^2_{30m} + \sigma^2_{100m}\\
&\sigma^2_{5m} + \sigma^2_{30m} + \sigma^2_{100m} + \sigma^2_{400m} = \sigma^2_{Total} \qquad (1)
\end{aligned}$$

The analysis permits the examination of changes in parameter values when moving from tree (5m) to stand (30m) to hill-slope (100m) to catchment (400m) scales. The analysis was performed in *GenStat for Windows* (v 12) and the models were fitted using residual maximum likelihood.

Within the nested framework, two soil core samples each were collected from 72 sites, using a GPS receiver to locate sampling points. Soils were separated into horizons and air-dried in a controlled environment (45°C) and then sieved through a 2-mm mesh. Total carbon and nitrogen in soil were determined using a Vario MAX CNS analyser (Elementar Analysensysteme GmbH) and clay content was measured by the Wet Pipette Method (Gee and Bauder 1986).

Results

Stations 1, 2 and 9 had higher carbon contents in B horizon of soil compared to those of other six stations while higher clay contents were observed in stations 1,2,3 and 6 (Figure 2).

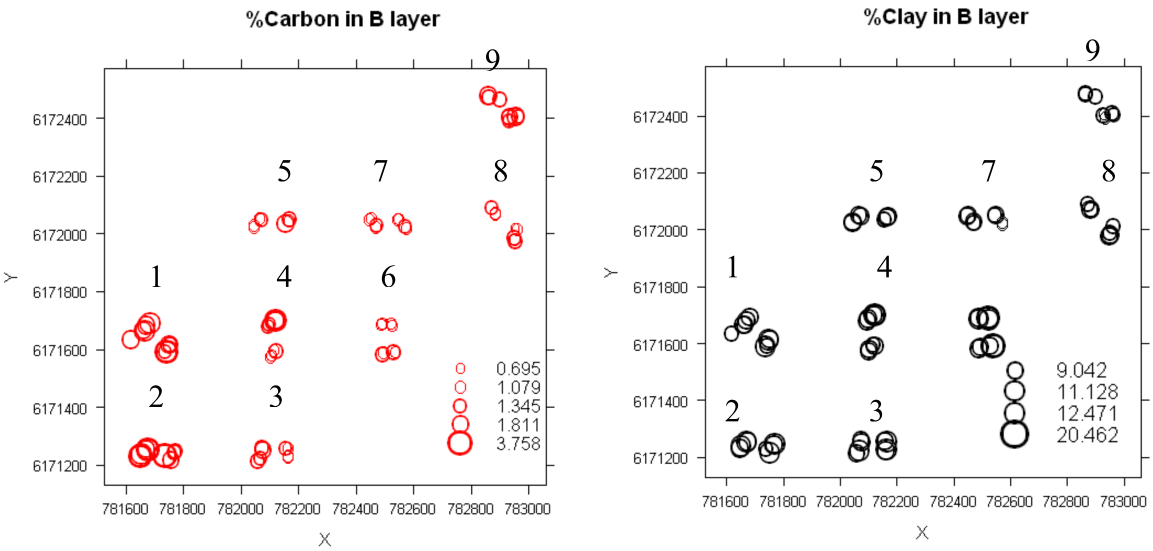

Figure 2. Spatial distribution of study sites at Arthursleigh showing proportional presentation of percentage soil carbon in B horizon (X and Y values are in meters - Projection GDA 1994 Zone 56)

The dominant spatial scales in terms of variation were 5m and 400m for both clay and carbon, each comprising about 40% of the variation (Tables 1 and 2). There are three soil types in the study area and the relief range from 0-26% at study sites. Therefore, we believe that the 400m scale represents variation attributable to soil type and topographic changes. Variation observed at the 5m scale is probably due to the low density of vegetation, where soils are unevenly exposed to sunlight.

Table 1. Carbon variances at each spatial scale

Scale	Variance	Var. Accumulated	%Var. at scale
5-m	0.234	0.234	41.3
30-m	0.0306	0.2646	5.4
100-m	0.0492	0.3138	8.7
400-m	0.2526	0.5664	44.6
Total	0.5664		

Table 2. Clay variances at each spatial scale

Scale	Variance	Var. Accumulated	%Var. at scale
5-m	4.811	4.811	50.4
30-m[1]	0	4.811	0
100-m	0.623	5.434	6.5
400-m	4.109	9.543	43.1
Total	9.543		

[1] The 30-m variance component was negative so it was constrained to a value of 0.

One implication of the results in terms of monitoring carbon is that it could help inform the size of the blocks needed to bulk samples from, when measuring soil carbon. The advantage of composite sampling is the reduction of analytical costs and residual variance but this is at the cost of losing degrees of freedom, which increases the precision of our estimates of a mean and/or a change in the mean. From the results here, a good starting point for composite sampling would be sampling from 5m blocks but there is little advantage for 30m or 100m blocks.

Conclusion and Future work

The dominant spatial scales in terms of variation were 5m and 400m for both clay and carbon, each comprising about 40% of the variation. The current study is the start of a long-term monitoring site for the Faculty of Agriculture, Food and Natural Resources in the University of Sydney. In mid-2010 probes will be installed at some sites to continuously monitor soil moisture and sap flow in trees. These will be augmented by monthly sampling campaigns where soil moisture and respiration will be measured at each site. From this we will use the method described by Lark (2005) to explore the scale-dependent nature of coupling between the carbon and water cycles.

In terms of monitoring carbon, future work should explore how nested designs can be used to identify the optimal size of blocks for composite sampling.

References

Gee GW, Bauder JW (1986) Particle size analysis. In 'Methods of soil analysis Part 1'. (Ed A Klute) pp. 383-411. (ASA and SSSA, Madison, WI).

Bureau of Meteorology (2010) http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications

Corstanje R, Lark RM (2008) On effective linearity of soil process models. *European Journal of Soil Science* **59**, 990–999,

Jackson RB, Jobbagy EG, Avissar R, Roy SB, Barrett DJ, Cook CW, Farley KA, le Maitre DC, McCarl BA, Murray BC (2005) Trading Water for Carbon with Biological Carbon Sequestration. *Science* **310**, 1944-1947

Lark RM (2005) Exploring scale-dependent correlation of soil properties by nested sampling. *European Journal of Soil Science* **56**, 307–317.

Youden WJ, Mehlich A (1937) Selection of efficient methods for soil sampling. *Contributions of the Boyce Thompson Institute for Plant Research* **9**, 59–70.

Nutrient release from *Eucalyptus grandis* and *Pinus taeda* harvest residues

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Abstract
Decomposition patterns of forest harvest residues produce the release of nutrients, which will be available for the next turn. Pine and eucalyptus harvest residues were aerobically incubated under controlled temperature (25ºC) for 300 days with the objectives: 1) to determine decomposition patterns of forest residues under controlled conditions, in relation to their physical and chemical characteristics, and 2) to evaluate nutrient release from the residues, comparing the results with those obtained in decomposition experiments in the field. The experiment consisted in six treatments and three replications. The treatments were: 1) control soil, 2) *P. taeda* needles, 3) *P. taeda* branches, 4) *E. grandis* leaves, 5) *E. grandis* bark, 6) *E. grandis* branches. The residues were cut into pieces and placed over the soil in the incubation pots. Soils were periodically leached to recover the released cations (Ca, Mg and K). Decomposition rates were estimated from evolved C-CO_2. The highest decomposition occurred in *E. grandis* leaves and *P. taeda* needles, which could be due to their higher soluble C and low C:N ratio compared to bark and branches. Among cations, K was easily leached while the opposite occurred with Ca.

Key Words
Forest harvest, nutrient leaching, soil respiration, potassium, calcium, magnesium.

Introduction
In commercial forests of Uruguay, the nutrient export with logs represents a minor proportion of the extracted nutrients (Hernández *et al.* 2009). Therefore, it is crucial to study decomposition patterns of forest harvest residues, after either clear cut or thinning, to evaluate the potential nutrient release from the residues. Residue decomposition depends on the characteristics of the materials (size and chemical composition), residue management and climatic conditions. The biochemical characteristics of residues influence decomposition patterns. Lignin is likely to retard decomposition because of its stability and detrimental effect on microbial growth (Berg and McClaugherty 1989). In contrast, a high content of soluble organic compounds is likely to promote the activity of microorganisms (Girisha *et al.* 2003). The decomposers population depends on C availability for energy, but they also need a certain amount of several other nutrients. Total N content and C:N ratios have been extensively considered as affecting decomposition rate of plant material (Burgess *et al.* 2002). When nutrients are scarce, decomposition rates are lower (Mary *et al.* 1996). Plant residues with low nutrient contents are likely to immobilize the required nutrients from the soil as decomposition proceeds. The immobilization of nutrients during decomposition often results in reduction of soil nutrient availability and also lower nutrient losses (Gómez Rey *et al.* 2008). The objectives of this study were: 1) to determine decomposition patterns of forest residues under controlled conditions, in relation to the physical and chemical characteristics of the residues, and 2) to evaluate nutrient release from the residues, comparing the results with those obtained in decomposition experiments in the field.

Methods
Soil and residue characteristics
For the incubation experiment, the soil from the 0-20 cm superficial layer of a thermic albic Argiudoll, Rivera (31º 22' 51.9''S and 55º 38' 31.4''W) was taken from a 12 year-old pine forest (Table 1). In this region the mean annual rainfall is 1,600 mm (evenly distributed) and the average temperatures of the coldest month (June) and the warmest month (January) are 11ºC and 24ºC, respectively. The harvest residues: *P. taeda* leaves and branches (diameter < 1 cm) and *E. grandis* leaves, bark and branches (diameter < 1 cm) were taken at harvest of commercial plantations (Table 2).

Table1. Chemical characteristics of the soil.

Total C	Total N	pH $_{(H2O)}$	pH $_{(KCl)}$	Ca^{2+}	Mg^{2+}	K^+	Na^+
(--------- mg/g ---------)				(----------$cmol_c$/kg ----------)			
8.05	0.73	4.24	3.74	1.45	0.7	0.18	0.38

Table 2. Chemical composition of harvest residues, and amounts of Ca, Mg, and K in the residues incorporated per pot.

Residue	Total C	Total N	Soluble C	Lignin	C/N	Ca	Mg	K	Ca	Mg	K
	(------------------- mg/g -------------------)					(------ mg/g -----)			(---------- mg/pot --------)		
Pinus needles	508.7	16.1	119.2	399.1	31	4.0	1.5	2.9	8.3	3.1	6.0
Pinus branches	493.6	4.7	78.9	370.7	105	3.0	1.4	1.7	10.4	4.9	6.0
Eucalyptus leaves	507.7	17.3	134.4	399.6	29	12.0	2.3	4.1	24.9	4.8	8.5
Eucalyptus branches	458.1	5.7	63.8	320.3	80	14.6	2.5	3.6	61.2	10.7	17.6
Eucalyptus bark	446.9	4.3	107.5	335.4	103	13.2	2.3	3.8	51.4	8.6	12.7

Incubation experiment

Mineralization patterns of forest residues were determined in an aerobic incubation experiment under controlled temperature (25ºC) for 300 days. The experiment consisted in 6 treatments and three replications. The treatments were: 1) control soil, 2) *Pinus taeda* needles, 3) *Pinus taeda* branches, 4) *Eucalyptus grandis* leaves, 5) *Eucalyptus grandis* bark, 6) *Eucalyptus grandis* branches. The soil for the incubation experiment, stored at field humidity, was crushed to pass a 5 mm mesh, and roots and litter were handpicked. The soil (25 g) was placed into a 50 mL plastic pot, with 5 small holes in the bottom and a filter paper to avoid soil losses. Plant residues were cut into 0.5 to 1 cm length pieces, and placed over the soil surface without mixing. The amounts (dry basis) were 2.08 g for pine needles and eucalyptus leaves, 3.52 g for pine and eucalyptus branches, and 4.64 g for eucalyptus bark. In order to measure the C-CO_2 evolved, the pots were placed into 1 L jars with a 5 mL vial with 0.5 M NaOH and hermetically sealed. Two extra jars were prepared to subtract the background C-CO_2. After the incubation period (1 week during the first 2 months and 2 weeks thereafter), the remaining NaOH was titrated with 0.1 M HCl, and the NaOH vials replaced. The incubation pots were leached every two weeks for the first 3 months, and once a month thereafter. For the leaching of the released nutrients, deionized water was poured over the residues in small drops for 15 minutes. The amount of water for the leaching was 80 mL at the beginning, when the incubation period was two weeks, and 160 mL for monthly samplings. The leachate was collected in 250 mL plastic flasks and stored at -4ºC.

Chemical analysis

Total and soluble C in residues were analyzed by oxidation with $K_2Cr_2O_7$ and concentrated H_2SO_4 at 150ºC for 1 hour, and colorimetric determination (Nelson y Sommers 1996). For total and soluble N determination, the Kjeldahl method was used. Total Ca, Mg, and K in residues were determined after ignition of the residues at 550ºC for 5 hours, and then ashes were diluted with HCl. Lignin was determined by acid hydrolysis. Soil exchangeable Ca, Mg, and K were extracted with 1 M NaH_4OAc at pH 7. The contents of Ca^{2+}, Mg^{2+} in the extracts and the leachate were analyzed by atomic absorption spectrometry, and K^+ by flame emission spectrometry.

Data analysis

The statistical analysis (ANOVA) was made at each sampling considering a completely randomized design with three replications. Differences among means ($P < 0{,}05$) were compared using Tukey analysis.
To characterize decomposition patterns an exponential model with two pools was adjusted:

$$w = w_r + w_d\, e^{(-kt)} \qquad (1)$$

where w is the remaining material at time t (percentage of initial weight), w_r is the estimated proportion of the pool resistant to decomposition, w_d is the proportion of decomposable material, k is the decay constant and t is the time in days.

Results

Carbon mineralization

Soluble C in the leachate was almost negligible compared to evolved C-CO_2 (data not shown). Figure 1 shows the cumulative evolved C-CO_2 from harvest residues, which were closely adjusted to the exponential decay model (Table 3). Decomposition rates of residues in this experiment were lower than those observed in field experiments (Hernández *et al.* 2009). One possible reason for this result is the effect of macrofauna in field experiments. Sunlight exposure and temperature fluctuations are also likely to contribute to higher decomposition in the field. The leaching regime, which removed the released nutrients, could also have negatively affected decomposers, because unlikely in the field situation, where rain is usually distributed along the year, the soils received a large amount of water in a short period. In this case it is possible that the microbial population was deprieved nutrients from soil and residues.

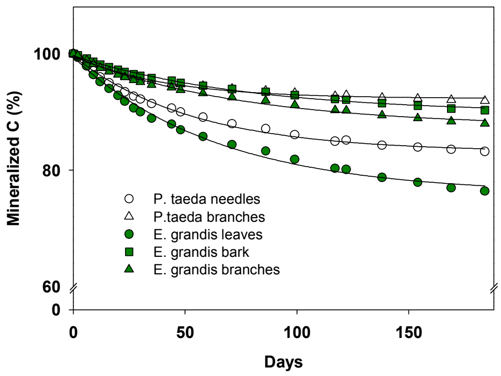

Figure 1. Mineralized C from harvest residues of *P. Taeda* and *E.grandis*.

Table 3. Parameters of the adjusted model: $w = w_r + w_d\, e^{(-kt)}$.

Residue	w_r	W_d	k	R^2
P. needles	83.12	16.46	0.019	0.99
P. branches	92.28	7.40	0.024	0.98
E. leaves	75.91	23.48	0.015	0.99
E. branches	87.45	12.06	0.013	0.99
E. bark	89.76	9.91	0.013	0.99

The fractions that experienced the highest decomposition were *E. grandis* leaves and *P. taeda* needles. This fact could be due to the higher soluble C and low C:N ratio of needles and leaves compared to bark and branches. Moreover, the fine sized residues (needles and leaves) could be easier to reach by decomposers than the coarse ones. *Pinus taeda* needles had significantly lower mineralization rates than *E. grandis* leaves throughout the study. A similar situation was observed for branches; *P. taeda* branches were the least decomposed residue at the end of the incubation, while bark was in the middle.

Release of Ca, Mg and K

The amounts of cations in the leachate showed an increasing trend in the first 60 days of incubation, slowing thereafter (Figure 2). This trend is coincident with the C-CO_2 evolution, and suggests that the cations were released as the material decomposed.

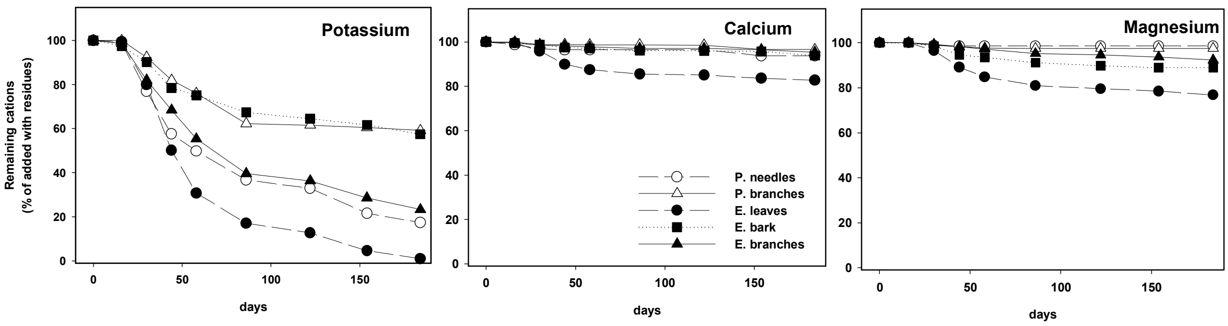

Figure 2. Remaining cations (K, Ca and Mg) from *P. Taeda* and *E.grandis* harvest residues in soils periodically leached (% of the initial amounts).

Potassium release from residues was rapid, and the amounts in the leachate were higher than the control at most sampling times. This result is coincident with decomposition studies in the field, which showed a rapid disappearance of K from harvest residues, attributed to leaching rather than to residue decomposition (Ganjegunte *et al.* 2003; Hernández *et al.* 2009). Moreover, K is less likely to be retained in exchangeable form by soil colloids when divalent cations (Ca and Mg) are released at the same time. Also, eucalyptus residues presented significantly higher K release than the same corresponding fraction (leaves or branches) for pine residues, which is coincident with their higher K content.

Magnesium concentration in leachate from eucalyptus residues was greater than control soil at most samplings, but this was not observed in pine residues. In field experiments with eucalyptus residues Hernández *et al.* (2009) reported Mg losses from residues which were closely linked to decomposition rates. On the other hand, the amounts of Ca in the leachate were similar in control soils and the soils amended with residues, except for eucalyptus leaves, which showed higher Ca release. Calcium is a structural component of vegetal tissues; consequently the Ca concentration in residues tends to increase as decomposition proceeds and it is only released at advanced stages of decomposition (Ouro *et al.* 2001). Considering the lower Ca and Mg content of pine residues compared to eucalyptus, it is possible that an important proportion of the divalent released cations from pine was retained in exchangeable forms in the soil, and hence, was not leached.

Conclusions

Decomposition of harvest residues followed an exponential decay trend with the highest losses corresponding to *P. taeda* needles and *E. grandis* leaves. Cation release followed a similar trend, with the lowest supply from coarse residues. While released K was easily leached, Ca and Mg tended to remain either within the residues or as exchangeable forms in the soil.

References

Berg B, McClaugherty C (1989) Nitrogen and phosphorus release from decomposing litter in relation to the disappearance of lignin. *Can. J. Bot.* **67**, 1148-1155.

Burgess MS, Mehuys GR, Madramootoo CA (2002) Nitrogen dynamics of decomposing corn residue components under three tillage systems. *Soil Sci. Soc. Am. J.* **66**, 1350-1358.

Gangegunte GK, Condron LM, Clinton PW, Davis MR, Mahieu N (2003) Decomposition and nutrient release from radiata pine (*Pinus Radiata*) coarse woody debris. *For. Ecol. Manage.* **187**, 197-211.

Gómez Rey MX, Vasconcelos E, Madeira M. (2008). Effects of eucalypt residue management on nutrient leaching and soil properties. *Eur. J. Forest Res.* **127**, 379-386

Hernández J, del Pino A, Salvo S, Arrarte G (2009) Nutrient export and harvest residue decomposition patterns of a *Eucalyptus dunnii* Maiden plantation in temperate climate of Uruguay. *For. Ecol. Manage.* **258**, 92-99.

Mary B, Recous S, Darwis D, Robin D (1996) Interactions between decomposition of plant residues and nitrogen cycling in soil. *Plant Soil* **181**, 71-82.

Nelson DW, Sommers LE (1996) Total carbon, organic carbon, and organic matter. In ´Methods of Soil Analysis. Part 3. Chemical Methods´. (Eds. DL Sparks *et al.*) pp. 961-1010. ASA and SSSA, Madison WI.

Ouro G, Pérez Batallón P, Merino A (2001) Effect of sylvicultural practices on nutrient status in a *Pinus radiata* plantation: Nutrient export by tree removal and nutrient dynamics in decomposing logging residues. *Ann. For. Sci.* **58**, 411-422.

Short-term effects of litter extraction on soil respiration, soil temperature and soil water content in a Sclerophyll forest of Central Chile

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Abstract
Litter extraction is a common practice in sclerophyll forests of Central Chile. This process has caused a long-term depletion of C substrates, thereby affecting biogeochemical balances, soil microbial populations, and plant germination. Evaluation of the effects of litter removal on biophysical parameters such as soil respiration, soil temperature and soil water content do not exist for this type of forest ecosystems. The aim of this study was to evaluate the short-term effect, caused by the extraction of soil organic layers in a peumo-boldo-litre forest ecosystem, in these biophysical parameters. Soil respiration, soil water content and soil temperatures at different depths were measured in a 24-days period. Immediate extraction of soil litter layers did not cause significant differences in soil respiration. In the consecutive sampling days, litter extraction caused significant decreases in soil respiration. Overall, the extraction of organic layers caused a decrease of about 33% in soil respiration. The extraction of soil organic layers, particularly the Oe+Oa layers might be responsible of the decrease in soil respiration. These layers contain considerable amounts of readily decomposable sources of C as well as microbial populations that could contribute to soil respiration. The decreased soil water content impeded a good correlation between soil T and soil respiration.

Key Words
Soil respiration, litter removal, sclerophyll forest, Chile.

Introduction
In the last decades, soil respiration has been considered one of the main fluxes of carbon in terrestrial ecosystems. Approximately 70% of CO_2 exchange between the forest ecosystem and the atmosphere comes from the soil (Raich and Schlesinger 1992; Granier *et al.* 2000). The soil respiration rate is controlled by the decomposition of soil organic matter (SOM), the inputs of plant debris, root respiration (Raich 1998), and soil environmental factors such as soil temperature and soil water content. Since an important fraction of soil respiration depends on litter decomposition, plant litter removal can reduce soil respiration up to 25% (Luo and Zhou 2006). In sclerophyll forests of Central Chile, litter removal is a common practice which has contributed to the degradation of these ecosystems, causing soil nutrient and SOM depletion, soil erosion and germination problems of tree seeds. Effects of litter removal on biophysical parameters have not been determined for this type of forest ecosystem. The aim of this study was to evaluate the short-term effects (i.e. first 20 days) of litter extraction on soil respiration, temperature, and soil water content in a sclerophyll forest of Central Chile. We also elevated the effect of temperature and soil water content on soil respiration. We hypothesize that litter extraction will made the declination of soil respiration as a consequence of changes in environmental factors and the depletion of SOC substrate.

Materials and methods
Study area and site description
The study area was located in Central Chile (34^{o}7'36"S, 71^{o}11'18"W; 247m above sea level) near the city of Santiago (Figure 1). The climate type of the zone is Mediterranean with a mean annual precipitation of 503 mm, and maximum and minimum annual air temperatures of 29 and 3^{o}C, respectively (CONAF 2008). The study site was located in a toe-slope position and represents a typical example of the natural vegetation of the region. However, the site has less anthropogenic disturbances compared with similar ecosystems of the region (i.e. harvesting and forest fires occurred around 50 years ago). The natural flora of the site is composed by peumo (*Cryptocarya alba* (Molina) Looser), boldo (*Peumus boldus Molina*), and litre (*Lithraea caustica* (Molina) H. et A.). The soil has developed from alluvial granitic deposits, with the particle-size distribution dominated by the silt fraction. It has well-developed organic layers (Oi, Oe, and Oa) on the surface and an A horizon rich in humified SOM.

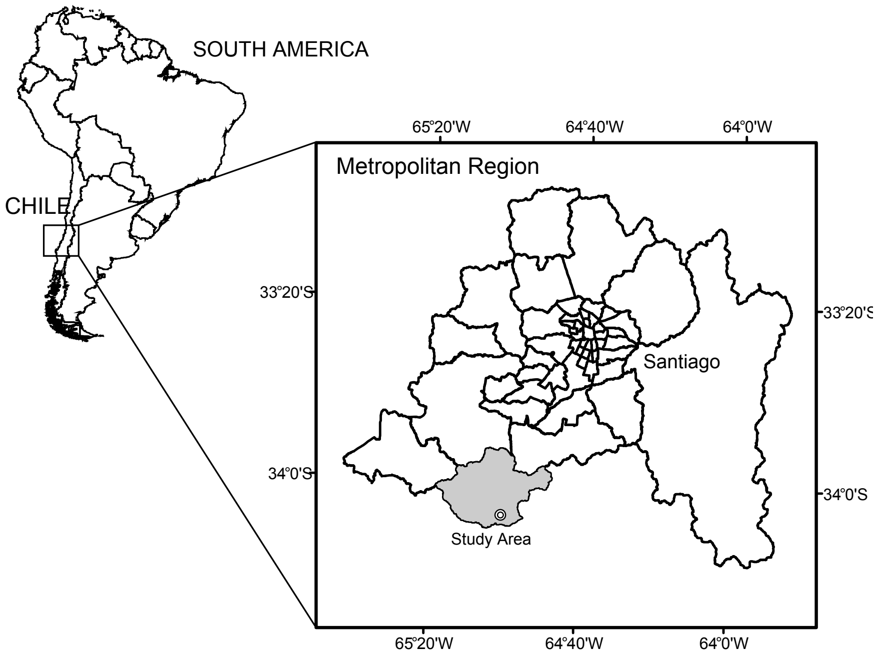

Figure 1. Location of the study area in the Metropolitan Region of Chile.

Experimental setup
A total of three plots of 10 x 10 m were selected. At each plot, 12 cylinders (polyvinyl chloride, 10 cm internal diameter, 8 cm length) were randomly installed. Cylinders were inserted manually, avoiding major soil and organic layers disturbances. One week after the insertion of the collars, soil litter layers (Oi and Oe+Oa) were extracted from six cylinders per plot. The litter extraction treatment (LE) represented the manual cleaning of an area of 0.56 m^2. The litter extracted was equivalent to 14.4 and 9.2 Mg/ha of the Oi and Oe+Oa layers, respectively. Cylinders with no litter extraction were considered as the control treatment (NLE).

Measurement of biophysical parameters
Soil respiration (R), volumetric soil water content (θ), and soil temperature (T) were measured immediately after the extraction of the organic layers and then, every four days for a total period of 24 days. Soil respiration ($gCO_2/m^2/h$) was measured with a portable infrared gas analyzer (Model EGM-4, environmental Gas Monitor System, PP Systems, USA). Volumetric soil water content in the top six-cm of soil, was determined with a time domain reflectometer connected to a datalogger (WET Sensor model WET-2, HH2 moisture meter, Delta-T Devices, UK). This sensor also includes a temperature sensor that allowed soil temperature determination at 6-cm soil depth. Soil temperature at 10.5- cm depth was measured using a digital thermometer (Checktemp 1, Hanna Instruments, USA). Surface soil temperature was also measured with an infrared thermometer (IR Wide Range Non-Contact Thermometer, Extech Instruments, USA) inside each cylinder, and immediately after the measurement of soil respiration.

Data analysis
Analysis of variance (ANOVA) was used to test for differences in R, θ, and T between treatments, and during the different days of measurements. The ANOVA model considered a complete randomized block design with one way treatment structure. Additionally, a correlation analysis was performed between T,θ, and R as the response variable.

Results
Immediate extraction of soil litter layers did not cause significant differences (p=0,437) in soil respiration. At day 4 however, and in the consecutive sampling days, litter extraction caused significant ($p<0.001$)) decreases in soil respiration. Comparing the means of all sampling days, the extraction of organic layers caused a decrease in about 33% as compared with the NLE treatment (Figure 2). This decrease is consistent with other studies that found similar effects under conifer forests (Ma *et al.* 2005). Temporal variation of soil respiration was not significantly correlated with θ or T. Soil water content was low during the trial (i.e. <0.25 m^3/m^3); thus the potential correlation between soil respiration and temperature was particularly weak. Rey *et al.* (2002) evaluating seasonal changes in soil respiration concluded that volumetric water contents lower

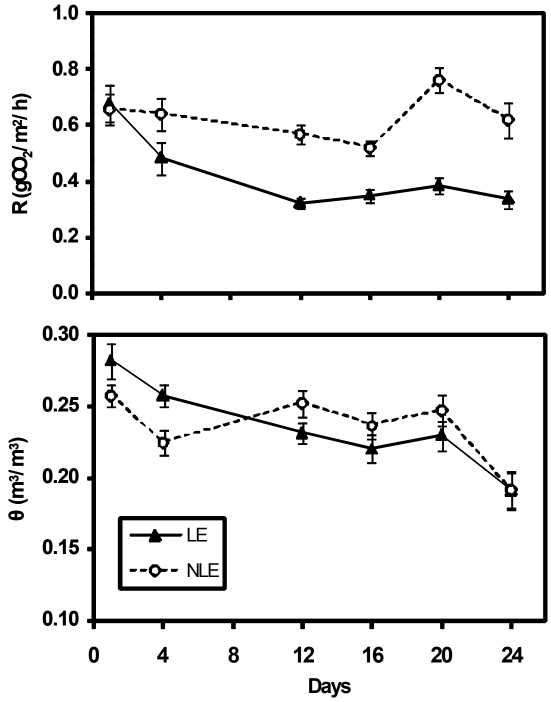

Figure 2. Temporal variation of soil respiration and volumetric water content in the top 6.5-cm depth in the litter extracted (LE) and no litter extracted (NLE) treatments. Differences between LE and NLE at days 1 and 4 are caused by a sampling artifact related to sampling depth. Error bars indicate ± one standard error of the mean.

than 0.20 m^3/m^3, can distort the relationship between R and T. The extraction of organic layers caused a significant increase in soil surface temperature (from 15.1 to 20.4 ^oC), which can be attributed to changes in surface albedo. At lower depths, soil temperature was not significantly affected by the extraction of the organic layers (Figure 3).

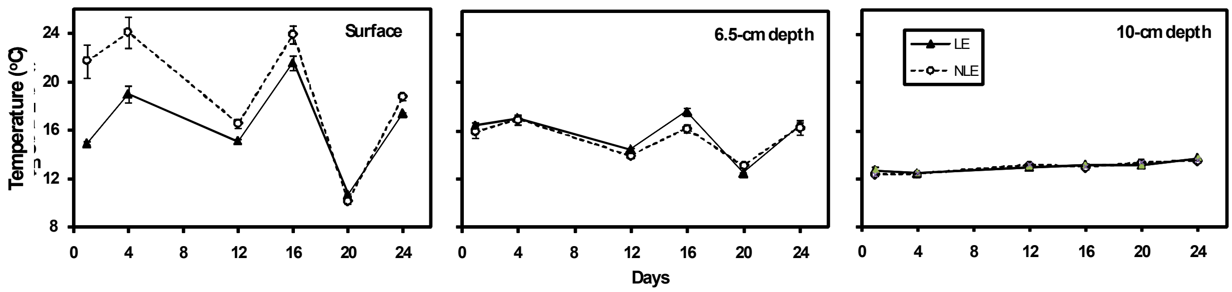

Figure 3. Temporal variation of soil temperature, at different depths, in the litter extracted (LE) and no-litter extracted (NLE) treatments. Error bars indicate ± one standard error of the mean.

Conclusions

The sclerophyll forest of Central Chile is characterized by an intensive use, particularly in terms of cattle activities and the extraction of forest litter. The later process has caused the degradation of the soil and the perturbation of the C balance. The results of this study showed that soil respiration decreased in the first days after the removal of organic layers. The main factor responsible for this variation seems to be related to the depletion of the organic substrate rather than changes in temperature and soil water content. Particularly, the removal of the more humified layers (Oe+ Oa) possibly created a lack of readily-available C sources and the extraction of a substantial population of the microorganisms responsible of C degradation.

Acknowledgements

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References

Corporación Nacional Forestal CONAF (2008) 'Plan de Manejo Reserva Nacional Roblería del Cobre de Loncha'.

Granier A, Ceschia E, Damesin C, Dufrene E, Epron D, Gross P, Lebaube S, Le Dantec V, Le Goff N, Lemoine D (2000) The carbon balance of a young beech forest. *Functional Ecology* **14**, 312–325.

Luo Y, Zhou X (2006) Soil Respiration and the Environment. 328 p. (Academic Press: USA).

Ma S, Chen J, Butnor J, North M, Euskirchen E, Oakley B (2005) Biophysical controls on soil respiration in the dominant patch types of an old-growth mixed conifer forest. *Forest Science* **51**, 221-232.

Raich J (1998) Aboveground productivity and soil respiration in three Hawaiian rain forests. *Forest Ecology and Management* **107**, 309–318.

Raich J, Schlesinger W (1992). The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus* **44**B, 81–99.

Rey A, Pegoraro E, Tedeschi V, de Parri I, Jarvis P, Valentín R (2002) Annual variation in soil respiration and its components in a coppice oak forest in Central Italy. *Global Change Biology* **8**, 851-866.

Soil carbon stocks estimation with reference to the degree of volcanic ash additions in Japanese forest soils

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Abstract
The objective of this study is to clarify the influence of volcanic ash addition on the soil carbon stocks and their accumulation process in Japanese forest soils. Volcanic ash additions to the soil were estimated based on the acid ammonium oxalate extractable aluminium (Alox) content, lithic fragment abundance and their vertical distribution patterns. The carbon in soil samples is controlled by Al-humus complex formation which is determined by the free Al generated from accumulated volcanic ash. The stratigraphical relationship of volcanic ash accumulation horizons affected the vertical distribution of carbon. In addition, successive accumulation of volcanic ash on the soil surface leads to development of the soil surface horizon and to increased soil carbon stock. These influences to soil carbon accumulation due to the degree of volcanic ash addition to soil resulted in variable soil carbon stocks among soil types reflecting the degree of volcanic ash addition. Our results suggest that volcanic ash addition controls the soil carbon stock of these Japanese forest soils.

Key Words
Volcanic ash, soil carbon stock, forest soil, Al-humus complex formation, free Al.

Introduction
Information on soil derived from volcanic ash will be important for evaluating and predicting the soil carbon stock. However, the method of estimation of volcanic ash additions is not established for the Japanese forest soils. The objectives of this study were to clarify the influence of volcanic ash addition on the soils and to classify these soils in detail based on their andic soil properties and to clarify the influence of volcanic ash addition on soil carbon accumulation in forest soils of Japan.

Methods
Soils
86 sola of Japanese forest soil such as Brown Forest soils (BFS), Black soils (BLS), Red soils (R) and Immature soils (Im) were used. These soils could be classified into Andosols, Umbrisols and Cambisols according to WRB 2006. Studied soils experience 7.5-16.2 ºC of mean annual air temperature, 1385-3641 mm of annual precipitation, and 37-1300 m of altitude. Various rocks, i.e., igneous, sedimentary, metamorphic, and volcaniclastic materials underlie these soils. These soils are under plantation forest of Japanese cedar or Japanese cypress and secondary forest of fagus, quercus and other broad leaved trees.

Chemical analysis
Total soil organic carbon was analyzed using the dry combustion method (MT-600 CN Corder Yanaco, Kyoto, Japan). Dry bulk density of the fine earth (< 2 mm) was measured by the core method (Soil Survey Laboratory 1996). The volume of lithic fragments was estimated from the lithic fragment abundances in the field profile description (Food and Agriculture Organization 1990). Acid oxalate extractable Al (Alox) and pyrophosphate extractable Al (Alpy) were determined using ISRIC methods (Reeuwijk 1993).

Soil carbon stock analysis
The soil carbon stocks were calculated for 0-30 cm depth, 0-100 cm depth and effective soil depth using the total soil organic carbon content, dry bulk density and abundance of lithic fragments.

Results
Volcanic ash additions to the soil were estimate based on the Alox content and lithic fragment abundance and their vertical distribution patterns. Therefore, BFS were classified in order of increasing volcanic ash additions to the soil parent material: H-Alox-NGv, H-Alox-Gv, M-Alox, and L-Alox. H-Alox-NGv BFS was characterized by an increase in the Alox content to ≥ 20 g/kg from the surface to subsurface horizons and a

near or complete absence of lithic fragment throughout the profile. H-Alox-Gv BFS was also characterized by Alox of ≥ 20 g/kg in the subsurface horizon but many lithic fragments were present in the surface and/or subsurface horizons. In the M-Alox BFS type, the maximum Alox content was > 4 g/kg but < 20 g/kg. In the L-Alox BFS type, the Alox content in the surface and subsurface horizons was < 4 g/kg.

Correlation with carbon amount, Alox amount and Alpy amount in the soil samples suggests that carbon amounts are controlled by Al-humus complex formation which is due to the free Al generated from accumulated volcanic ash (Figure 1). Comparison between vertical distribution patterns of carbon amount, Alox amount and Alpy amount show that stratigraphical relationships of volcanic ash accumulated horizons and carbon amounts. In addition, successive accumulation of volcanic ash on the soil surface which is shown by the vertical distribution pattern of Alox, leads to development of the soil surface horizon and increases the soil carbon stock. The soil carbon stocks were larger in the order BLS > H-Alox-NGv BFS, H-Alox-Gv BFS > M-Alox BFS > L-Alox BFS, R and Im (Table 1). These influences on the soil carbon accumulation process by the degree of volcanic ash additions to soil have resulted in various the soil carbon stocks among the soil types reflecting the degree of volcanic ash addition.

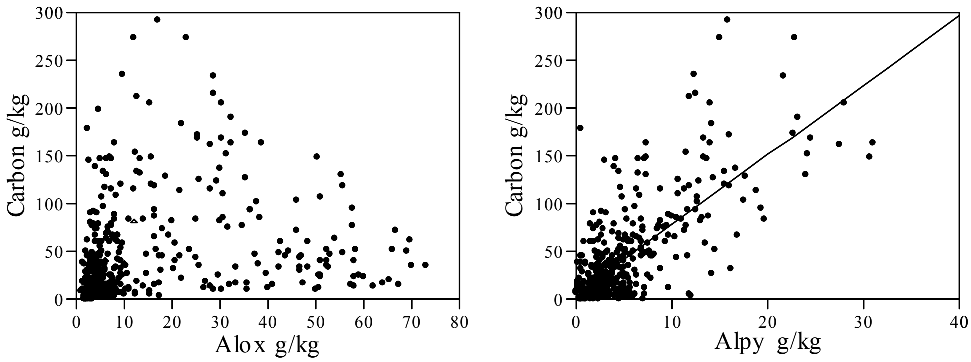

Figure 1. Relationships between carbon contents and Alox, Alpy contents in the soil samples.

Table 1. Soil carbon stocks in each soil type according to the advanced classification.

Soil type (number of sola)	Volcanic ash addition	0-30cm	0-100cm	Effective soil depth
			(kg/m^2)	(cm)
BLS (6)	Accumulated	14.8	35.6	41.8
H-Alox-NGv BFS (6)	Accumulated	12.2	23.8	33.2
H-Alox-Gv BFS (7)	Highly mixed	10.3	18.5	22.3
M-Alox BFS (45)	Lowly mixed	7.1	10.5	11.1
L-Alox BFS (17)	Absent	4.5	6.6	6.2
R (3)	Absent	5.1	6.7	7.0
Im (2)	Absent	2.9	3.4	3.1

Conclusion

Degree of volcanic ash additions to the soil could be estimated using the BFS classification and based on Alox content, lithic fragment abundance and their vertical distribution patterns, as proposed in this work, and can provide insight into different pedogenetic processes. We found that the volcanic ash additions control the soil carbon stocks of Japanese forest soils.

References

Food and Agriculture Organization (1990) Guidelines for soil description, 3rd edn. (Food and Agriculture Organization, Rome).

Reeuwijk LP (1993) Procedures for Soil Analysis. Technical paper 9. (International Soil Reference and Information Centre, Wageningen).

Soil Survey Laboratory (1996) Bulk density cores field moist (4A3a). In 'Soil Survey Laboratory Methods Manual'. Soil Survey Investigations Report No. 42 ver. 3.0, pp. 137-138. (NRCS, USDA: Washington DC).

Soil nutrients, aboveground productivity and vegetative diversity after 10 years of experimental acidification and base cation depletion

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Abstract
Soil acidification and base cation depletion are concerns for those wishing to manage central Appalachian hardwood forests sustainably. In this research, 2 experiments were established in 1996 and 1997 in two forest types common in the central Appalachian hardwood forests, to examine how these important forests respond to depletion of nutrients such as calcium and magnesium. After 10 years of treatment, relatively few effects were detected on soil nutrients or total aboveground biomass. This research will continue to monitor effects as the stands develop and as nutrient uptake and cycling changes over time.

Key Words
Calcium depletion, vegetative diversity, liming, forest sustainability.

Introduction
Concerns have existed for many years about nutrient depletion of forest soils, either through harvesting, acidic deposition or other causal agents. In the central Appalachians, where both acidic deposition and forest harvesting have been occurring for many decades, depletion of soil calcium and magnesium is a particular concern. The forests of the central Appalachians are generally quite productive, and highly diverse, and serve many important functions including providing recreational opportunities, supporting wood-based industries and communities, providing wildlife habitat, and ensuring delivery of ecosystem services. In 1996, a study was begun to assess the effects of base cation depletion on long-term productivity of soil and forest vegetation in the central Appalachians. These studies are affiliated with the international Long Term Soil Productivity Study (Powers *et al.* 2005). Our objectives were: (1) Characterize the productivity, diversity and biogeochemistry of a forest system hypothesized to be sensitive to base cation removals. (2) Determine the response of this forest community to base cation removal, and (3) Create new and modify existing vegetation, nutrient cycling, hydrologic models to describe and simulate forest change in response to base cation removals, nitrogen and sulfur inputs and mitigating base additions. This presentation will focus on the second objective.

Site descriptions
Two sites were used in this study, the Fork Mountain study site, and the Middle Mountain study site, both located in West Virginia, within the central Appalachian mountains. The Fork Mountain site is also located within the Fernow Experimental Forest, a research area set aside in 1934 and dedicated to long-term forestry research (Adams *et al.* in press). These sites represent 2 distinct forest types (Table 1), with similar treatments and experimental designs (Adams *et al.* 2004).

Methods
To induce base cation depletion a combination of treatments was used; whole-tree harvesting was used along with removal of all down dead wood, to effect removal of aboveground nutrient pools, and minimize cycling from these pools (Whole-tree harvest, WT). Ammonium sulfate fertilizer was applied 3 times per year at 35 kg N/ha/yr, and 40 kg S/ha/yr to accelerate leaching of calcium and magnesium from the soil (WT+NS). This rate was approximately twice the ambient throughfall inputs (Adams *et al.* 2006). In addition, dolomitic lime (WT+NS+LIME) was applied at a rate of 22.5 kg Ca/ha/yr and 11 kg Mg/ha/yr (a rate twice that of export from an untreated reference watershed (Adams *et al.* 1997), to evaluate whether simple replacement of these nutrients is effective. On the Middle Mountain site, a treatment of WT plus lime additions (LIME) was added.

These experiments are designed to last for approximately 80 years. We report on soil and vegetation measurements collected prior to and during the first 10 years.

Table 1. **Characteristics of the Fork Mountain and Middle Mountain long term soil productivity study sites.**

	Fork Mountain	Middle Mountain
Forest type	Mixed hardwoods	Cherry- maple , some red spruce
Age of forest stand (yrs)	~80	~90
Soil type	Loamy skeletal, mixed, mesic typic Dystrochrepts	Loamy skeletal, mixed, active, frigid typic Dystrudepts
Elevation (m)	790-850	1100-1250
Experimental treatments	4 blocks of 4 treatments – Uncut control – WT only – WT+fertilizer – WT+fertilizer+lime	4 blocks of 5 treatments – Uncut control – WT only – WT+fertilizer – WT+fertilizer+lime – WT+lime

Results

Soil chemistry

Ten years after the experiments began; the only detectable treatment effects on soil nutrients appear related to the liming treatment. Changes in soil pH due to the LIME treatment were noted at the more acidic the Middle Mountain study site (Figure 1). The liming treatment increased soil magnesium (Mg) levels significantly in all 3 depths studied on the Fork Mountain site (Figure 2), but there were no statistically significant treatment effects on soil exchangeable calcium. Soil carbon in the upper soil horizons of the liming treatment also appear to have increased after 10 years, but the effect is not statistically significant.

Vegetation

Total aboveground wood biomass did not differ among treatments (Johnson *et al.* in press) on the Fork Mountain site after 10 years. An analysis of treatment effects at the species level suggests, however, that some tree species, notably *Liriodendron tulipifera* and *Magnolia acuminata*, demonstrated increased diameter growth and accumulated significantly greater biomass in the WT+NS+LIME treatment than in the other treatments. These tree species are known to acquire and utilize more Ca and possibly Mg in their bolewood. Species richness declined at both sites over the 10 year period, presumably due to the changes in microclimate following the whole-tree harvesting treatment, although richness also declined in the uncut control plots on the Fork Mountain site. Vegetative species richness, which included trees, shrubs and herbaceous vegetation, declined from 75 to 57 species during the 10-year period on the Fork Mountain site, and from 40 to 32 species on the Middle Mountain site during the 10 years.

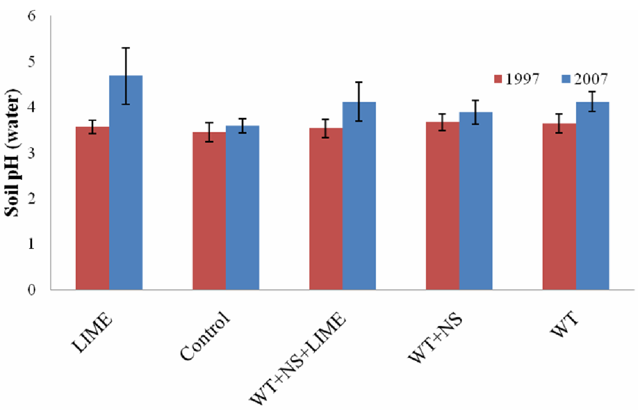

Figure 1. Mean A horizon soil pH, Middle Mountain site. N=12. Bars represent ± standard deviation.

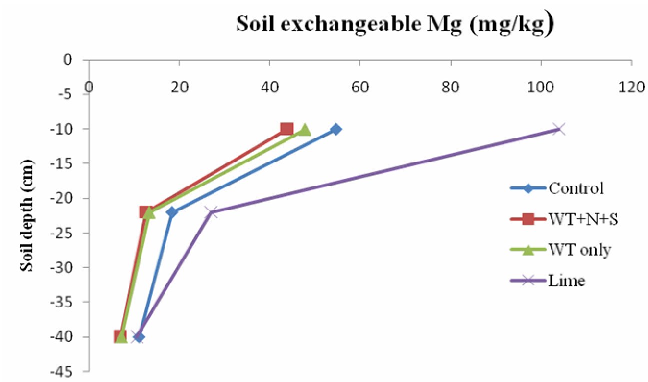

Figure 2. Mean soil Mg concentrations, Fork Mountain site, by soil depth and by treatment.

Conclusions

Ten years into these 80-year experiments, relatively few effects directly attributable to the chemical treatments have been detected. While there is clearly an effect of the whole tree harvesting on vegetative productivity and diversity, we cannot yet detect soil acidification from the fertilization treatments. Only the liming treatment appears to have had an effect on soil chemistry, and this effect appears to be due to the magnesium in the lime, rather than a calcium effect. Soil magnesium levels are so low, that even adding a small amount has resulted in a significant increase in available magnesium. We will continue to follow forest development and effects on soil and soil solution chemistry to better understand how these hardwood forests respond to changes in availability of important nutrients over time.

References

Adams, MB, Angradi TR, Kochenderfer JN (1997). Streamwater and soil responses to five years of nitrogen and sulfur additions at the Fernow Experimental Forest, West Virginia. *Forest Ecology and Management* **95**, 79-91.

Adams, MB, Burger J, Zelazny L, Baumgras, J (2004). 'Description of the Fork Mountain long-term soil productivity study: site characterization'. Gen. Tech. Rep. NE-323 (US Department of Agriculture Forest Service, Northeastern Research Station: Newtown Square, PA, USA)

Adams, MB, DeWalle, DR, Hom, JL (2006) 'The Fernow Watershed Acidification Study'. (Springer: Dordrecht, The Netherlands).

Adams, MB, Edwards PJ, Ford WM, Schuler TM, Thomas-Van Gund, M, Wood, F (in press) 'Fernow Experimental Forest – Research History and Opportunities'. (US Department of Agriculture Forest Service: Washington, D.C.)

Johnson, BA, Piatek KB, Adams MB, Brooks JR (in press) Does nitrogen and sulfur deposition affect forest productivity? In 'Proceedings: Conference on the Ecology and Management of High-Elevation Forests of the Central and Southern Appalachian Mountains'. (Eds J Rentch, TM Schuler) (US Department of Agriculture, Forest Service, Northern Research Station. Newtown Square, PA).

Powers, RF, Scott DA, Sanchez FG *et al.* (2005) The North American long-term soil productivity experiment: Findings from the first decade of research. *Forest Ecology and Management* **220**, 31-50.

Spatiotemporal distribution pattern of soil temperature in forest gap in *Pinus koraiensis*-dominated broadleaved mixed forest in Xiao Xing'an Mountains, China

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Abstract
By using regular grid and transect methods, plot and sub-plots were established in the forest gap of *Pinus koraiensis*-dominated broadleaved mixed forests in Xiao Xing'an Mountains, China. The surfacial, maximum and minimum temperature(T_s, T_{max}, and T_{min}), and the temperature at 5, 10, 15, and 20cm soil depths were measured from May to September 2006 to illustrate their spatiotemporal distribution patterns. The results showed that high-value regions of daily T_s were not at the gap center, but at north-western and eastern sides of the gap, with an asymmetric distribution. Their mean difference between daily T_{max} and T_{min} was bigger in the trees early and late growth periods, but relatively smaller in fast growth period. As for daily and monthly mean soil temperatures over soil depths, a bimodal behavior was observed in east-west direction. Daily and monthly mean temperature exhibited no apparent and single peak behavior in north-south direction, except in May, respectively.

Key Words
Pinus koraiensis-dominated broadleaved mixed forest, forest gaps, soil temperature, distribution pattern.

Introduction
Forest gaps exist widely in forest ecosystems, are in an important phase of forest cycle regeneration. Environmental heterogeneity caused by gap formation, its impact on species distribution, population dynamics and species diversity in forest gaps, and its important roles in forest succession, regeneration and growth have been widely concerned (Poulson and Platt 1989; Beckage *et al.* 2000; Fownes and Harrington 2004; Pedersen and Howard 2004; Diaci *et al.* 2005). Microclimatic difference between and within canopy gaps (De Freitas and Enright 1995), light index and its application in Sweden (Dai 1996), microclimate (Carlson and Groot 1997), states of partially microclimatic factors after gap formation and soil moisture response (Canham *et al.* 1990; Gray *et al.* 2002; Clinton 2003; Raymond *et al.* 2006) were systematically performed. Over the past decade, our researches on forest gaps gradually increased in China (Zang RG *et al.* 1999), but so far, those on microclimate in gaps have been not yet fully developed, particularly on spatiotemporal distribution patterns of soil temperature after gap formation is still rare. Only a fewer researchers investigated the microclimate in gaps, their researches mainly dealt with light, spatiotemporal distributions of air and soil temperature (Zang RG *et al.* 1999; Zhang YP *et al.* 2001)) as well as other microclimatic factors (Liu WJ *et al.* 2000a; Zhang YP *et al.* 2002, 2003; Zhu JJ *et al.* 2007), and microclimatic difference (Liu WJ *et al.* 2000b). However, studies on spatiotemporal distribution of soil temperature are still scarce (Zhang YP *et al.* 2001; Zhu JJ *et al.* 2007). In vast temperate regions, studies on the changes in soil temperature after gap formation are even rarer (Li Y *et al.* 2007; Zhu JJ *et al.* 2007). Therefore, measurement plot and sub-plots were established, spatiotemporal distribution pattern of soil temperature in this forest gap was analyzed in order to provide basic data for researches on environmental heterogeneity and regeneration in canopy gaps, sustainable ecosystem management.

Materials and methods
Study site and experimental design
Investigations were performed from May to September 2006 in a gap created naturally in *Pinus koraiensis*-dominated broadleaved mixed forests in Xiao Xing'an Mountains, in Liangshui National Nature Reserve (47°06′49″–47°16′10″N, 128°47′8″–128°57′19″E) of Northeast Forestry University, in Dailing District, Yichun City, Heilongjiang Province, China. For a more in-depth description of this Reserve, see Duan *et al.* (Duan *et al.* 2009). The study site is located in broad-leaved *Pinus koraiensis* forests at an elevation of 420 m, with negative slope, a slope grade of 10–15°, a northern aspect. The plot area was 20 m×20 m. Canopy gap was irregularly shaped with about 200 m^2 area, naturally created by multiple gap-makers at unknown time in the past. The reason for gap formation is more complicated, such as breakdown, snag, and tree-fallen. Tree species surrounding the gap boundary are mainly *Pinus koraiensis* and *Betula costata* with their average

height of 17.5 m. For the details of this site, see Duan *et al.* (Duan *et al.* 2009). Measurements done from May to September 2006 in this study area included surfacial, maximum and minimum temperature in a grid design (Figure 1), and the temperature at 5, 10, 15, and 20 cm soil depths along two perpendicular transects (Figure 2).

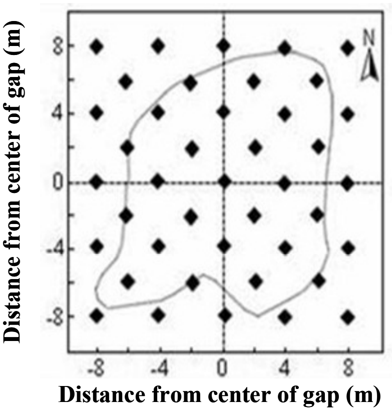

Figure 1. Locations of measurement plots of T_s, T_{max} and T_{min}. The black line indicates the approximate contour of the gap.

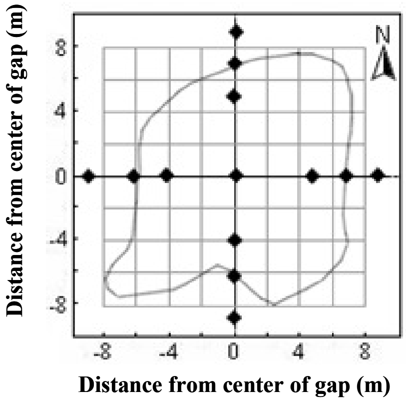

Figure 2. Locations of measurement plots of soil temperature at 5, 10, 15, and 20 cm soil depth. The black line indicates the approximate contour of the gap.

Soil temperature measurements

41 locations of measurement sub-plots were selected in the forest gap and around its edge by using regular grid and transect methods, surfacial, maximum and minimum thermometer were placed at each location (Figure 1). Other 13 locations of measurement sub-plots were located at gap center (GC), gap edge (GE), expanded gap edge (EG), understory (US) along two transects running North-South and West-East directions through gap center. Bended-tube thermometers were installed in each location to measure the temperature at 5, 10, 15, and 20cm soil depths (Figure 2). Measurement was done from 6:00h to 18:00h for 6-10 days monthly, time interval was 2 hours.

Data progressing

Soil temperature, which was not directly measured in other locations in the gap, was assessed by estimation of spatially local Kriging interpolation from geographical statistics (Wang SP *et al.* 2003). SPSS 11.5 and GS+For Windows 3.11 softwares were used for basically and spatially statistical analysis on the data, respectively. SURFER 7.0 software (Golden Software 1999) was used for estimation of spatially local Kriging interpolation and further mapping of soil temperature.

Results

Spatiotemporal distribution pattern of soil temperature in forest gap

Daily spatial distribution pattern of soil surface temperature in forest gap

Daily spatial distribution pattern of T_s in forest gap in July was set as an example (Figure 3). In general, within a day, the high-value region of T_s happened with the sequence of north-western, northern and eastern sides of the gap, T_{max} within the high-value region was 27.0 ^oC (14:00h)＞25.0 ^oC (12:00h)＞23.0 ^oC (10:00h)＞22.0 ^oC (16:00h).

Monthly spatial distribution pattern of soil surface temperature in forest gap

For the distribution of T_s, all high-value regions in months appeared in eastern side of the gap, but their T_{max} was different, relatively higher from June to August; the secondary high-value regions occurred in northwestern side of the gap every month, but their gradients were all smaller. All high-value regions of T_s were not in the central gap, but in eastern and northwestern side of the gap, their distribution was asymmetric (Figure 4).

Spatiotemporal distribution pattern of difference between daily Tmax and Tmin in forest gap

In the early growing season (May), the diurnal range of T_s was bigger, reached 21.0 ^oC in northwestern side of the gap (Figure 5). That was smaller from June to August than that in May, there was a decreasing tendency; while in the late growing season, it was larger in September than in August. Comparatively higher mean difference between daily T_{max} and T_{min} in our study area was all located in northwestern and eastern side of the gap.

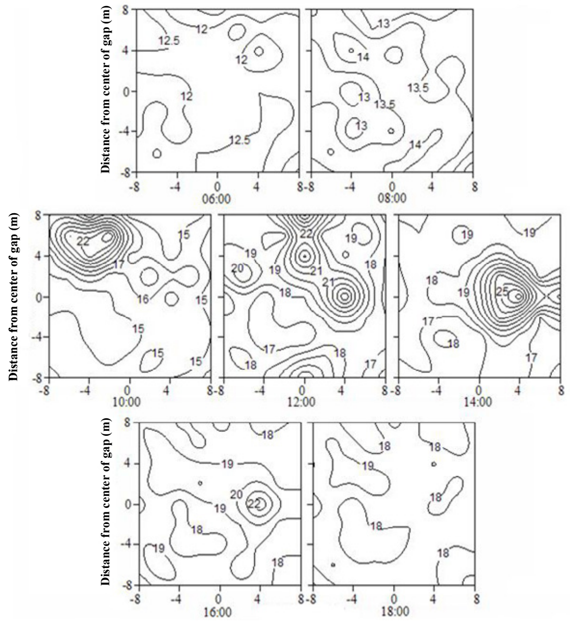

Figure 3. Diurnal spatial distribution pattern of soil surface temperature in the gap (□).

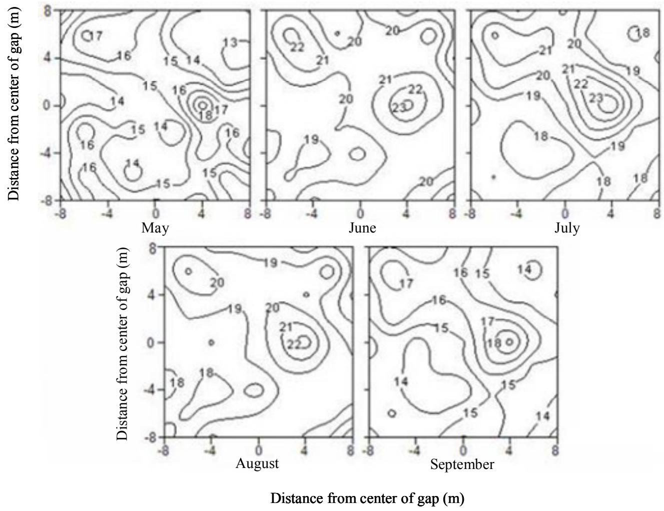

Figure 4. Monthly spatial distribution pattern of soil surface temperature in the gap (□).

Soil temperature along different directions in forest gap

The diurnal variation in soil temperature along different directions

A bimodal behavior of soil temperature at all locations was observed in east-west direction (Figure 6), their bimodal values were respectively located in expanded gap edge in western side and in canopy gap edge in eastern side; An unapparent single peak behavior at all locations was found in north-south direction, the positions of their bimodal values changed weakly over time and shifted between in canopy gap edge in northern side and in the center of gap, but in general, the soil temperature in northern side was larger than that in southern side. By contrast, it was comparatively smaller under understory. The magnitude of change in soil temperature at 5 cm depth was the highest (2 ~7 ^{o}C) in daytime, the lowest at 20cm depth (0 ~2 ^{o}C).

The monthly variation in soil temperature along different directions

Generally, a bimodal behavior was observed in east-west direction every month (Figure 7), bimodal values occurred in gap edge in eastern side and in expanded gap edge in western side, respectively, bimodal value in the eastern side was larger than that in western side. Monthly mean soil temperatures except in May in north-south direction exhibited an unapparent single peak behavior, bimodal value appeared in the central gap and in expanded gap edge in northern side over time, and meanwhile soil temperature in northern side was slightly higher than that in southern side.

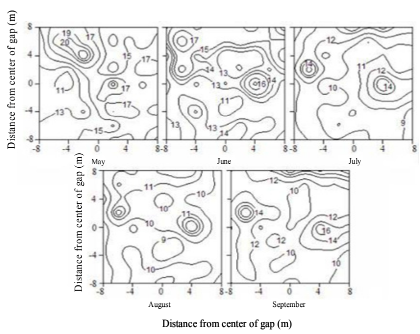

Figure 5. Spatial distribution of difference between daily Tmax and Tmin in the gap.

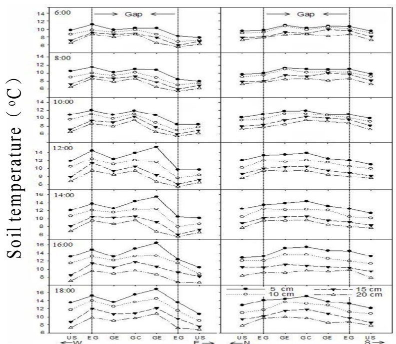

Figure 6. Diurnal variation of soil temperature at different directions in the gap.

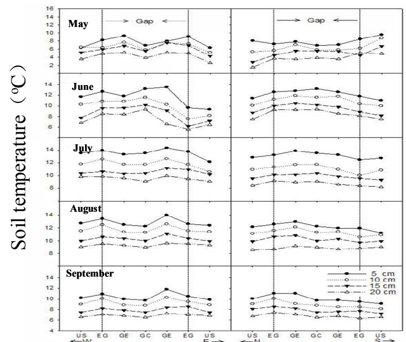

Figure 7. Monthly variation of soil temperature at different directions in the gap.

Conclusion

For the high-value regions of T_s in the gap, there was apparent diurnal variation, with the sequence of north-western, northern and eastern sides of the gap, those were all located in north-western and eastern side with an asymmetric distribution every month; Mean difference between daily T_{max}-T_{min} was larger in the tree's early and late growth periods, but relatively smaller in fast growth period. Comparatively higher diurnal range was all in north-eastern and eastern side of the gap; As for daily and monthly mean soil temperatures at 5, 10, 15, and 20 cm depths, a bimodal behavior was observed in east-west direction, daily bimodal values were respectively located in expanded gap edge in western side and canopy gap edge in eastern side, monthly bimodal values occurred in gap edge in eastern side and expanded gap edge in western side, respectively; Daily and monthly mean temperature exhibited no apparent and single peak behavior in north-south direction, except in May, respectively.

Acknowledgements
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References

Beckage B, Clark JS, Clinton BD *et al.* (2000) A long-term study of tree seedling recruitment in southern Appalachian forests: The effects of canopy gaps and shrub understories. *Canadian Journal of Forest Research* **30,** 1617-1631
Canham CD, Denslow JS, Platt WJ *et al.* (1990) Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. *Canadian Journal of Forest Research* **20,** 620-631
Carlson DW, Groot A (1997) Microclimate of clear-cut, forest interior, and small opening in trembling aspen forest. *Agricultural and Forest Meteorology* **87,** 313-329
Clinton BD (2003) Light, temperature, and soil moisture responses to elevation, evergreen understory, and small canopy gaps in southern Appalachians. *Forest Ecology and Management* **186,** 234-255
Dai XB (1996) Influence of light condition in canopy gaps on forest regeneration: A new gap light index and its application in a boreal forest in east-central Sweden. *Forest Ecology and Management* **84,** 187-197
De Freitas CR, Enright NJ (1995) Microclimatic difference between and within canopy gaps in a temperate rainforest. *International Journal of Biometeorology* **38,** 188-193
Diaci J, Pisek R, Boncina A (2005) Regeneration in experimental gaps of subalpine *Picea abies* forest in the Slovenian Alps. *European Journal of Forest Research* **124,** 29-36
Duan WB, Wang J, Li Y (2009) Microenvironmental heterogeneity of physical soil properties in a broad-leaved Pinus koraiensis forest gap. *Frontiers of Forestry in China* **4**, 38–45
Fownes JH, Harrington RA (2004) Seedling response to gaps: Separating effects of light and nitrogen. *Forest Ecology and Management* **203,** 297-310
Gray AN, Spies TA, Easter MJ (2002) Microclimatic and soil moisture response to gap formation in coastal Douglas-fir forests. *Canadian Journal of Forest Research* **32,** 332-343
Golden Software (1999) 'Surfer 7® —A Program for Contouring and 3D Surface Mapping for Scientists and Engineers'. (Golden, Colorado).
Li Y, Duan WB, Chen LX *et al.* (2007) Microenvironmental variation feature of soil surface temperature in a broad-leaved Korean pine forest gap. *Science of Soil and Water Conservation* **5,** 81-85 (in Chinese)
Liu WJ, Li QJ, Zhang GM *et al.* (2000a) Microclimatic characteristics of canopy gaps in *Shorea chinensis* forest in Xishuangbanna. *Chinese Journal of Plant Ecology* **24**, 356-361 (in Chinese)
Liu WJ, Li QJ, Zhang GM *et al.* (2000b) The microclimatic differences between and within canopy gaps in the dry-hot season in *Shorea chinensis* forest. *Acta Ecologica Sinica* **20**, 932-937 (in Chinese)
Pedersen BS, Howard JL (2004) The influence of canopy gaps on overstory tree and forest growth rates in a mature mixed-age, mixed-species forest. *Forest Ecology and Management* **196,** 351-366
Poulson TL, Platt WJ (1989) Gap light regimes influence canopy tree diversity. *Ecology* **70,** 553-555
Raymond P, Munson AD, Ruel JC *et al.* (2006) Spatial patterns of soil microclimate, light, regeneration, and growth within silvicultural gaps of mixed tolerant hardwood-white pine stands. *Canadian Journal of Forest Research* **36,** 639-651
Zang RG, Liu JY, Dong DF (1999) Gap Dynamics and Forest Biodiversity. Beijing: China Forestry Press, (in Chinese)
Zhang YP, Dou JX, Ma YX *et al.* (2003) Temporal-spatial distribution characteristics of microclimate in tropical secondary forest canopy gap in Xishuangbanna**.** *Chinese Journal of Applied Ecology* **14**, 2129-2135 (in Chinese)
Zhang YP, Ma YX, Liu YH *et al.* (2001) Characteristics of spatial distribution of microclimate in the gap of ever-green broad-leaved forest in the north of Ailao Mountain in Yunnan**.** *Journal of Beijing Forestry University* **23**, 80-83 (in Chinese)
Zhang YP, Wang JX, Ma YX *et al.* (2002) The temporal-spatial distribution of temperature on the surface roughtness of the tropical secondary gap in Xishuangbanna, Yunnan Province. *Scientia Silvae Sinicae* **38**, 1-5 (in Chinese)
Zhu JJ, Tan H, Li FQ *et al.* (2007) Microclimate regimes following gap formation in a montane secondary forest of eastern Liaoning Province, China. *Journal of Forestry Research* **18**, 167-173
Wang SP, Sun ZQ, Wu J *et al.* (2003) Spatial heterogeneity of characteristic functional parameter of soil water movement: Mathematical approaches, sampling scheme, influencing factors. *Science of Soil and Water Conservation* **1**, 95-98 (in Chinese)

Substrates used in SIR assays can inhibit basal respiration in rewetted soil

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Abstract
Respiration assays are routinely used for investigating microbial metabolic activity in soil, but usually after a period of "conditioning" whereby dry soil is rewetted and incubated for a period of days. We showed that rewetting and incubation of soil with or without amendments cause changes in microbial populations that are dependent on the type of amendment. As these amendments resulted in altered basal respiration levels and SIR profiles, they call into question the suitability of soil conditioning as pretreatment for soil microbial analyses. When testing soils from an experiment involving various amendments we have found that different substances can inhibit, rather than stimulate, respiration following rewetting. We suggest further investigation of "CO_2 burst inhibition" for the purpose of developing a method that does not require naturally dry or air dried soil to undergo conditioning prior to a SIR assay.

Key Words
Soil, SIR, rewetting, amendment, conditioning.

Introduction
One method widely employed for monitoring soil microbial status is to quantify respiration in soil after the addition of a simple carbon source: Substrate Induced Respiration (SIR) (Anderson and Domsch 1987; Degens and Harris 1997). Miniaturisation of the assay by Campbell *et al*. (2003) allowed complex analyses of soil microbial "physiological profiles" at the community level (CLPP) to be performed quickly and inexpensively (for review see Chapman *et al.* 2007). CLPP has been used to assess the effects of pollutants (Kaufmann 2006), amendments (e.g. Degens *et al.* 2000) and landuse change (Lalor *et al.* 2007) on soils. However, while this method can contribute useful data to many areas of environmental science, agriculture and forestry; variability within and between soils becomes an obstacle to establishing a robust and versatile protocol. Soil conditioning has been used as one means of reducing this variability. It can also prevent the dramatic but short-lived increases in soil respiration occurring upon rewetting of dry soil (the "CO_2 burst") (Fierer and Schimel 2003) that impact the SIR assay. In our investigations of soil pretreatment and optimal CLPP assay conditions, we have observed that substrate addition during assays sometimes decreased, rather than increased, soil respiration. In order to explain these surprising results we examined the effects of various soil amendments, including some of the substrates used in SIR assays, on basal and substrate-induced respiration in sandy soil from the south-west of Western Australia (WA). We hypothesised that rewetting of the soil as well as addition of soil amendments will modify respiration levels and patterns in SIR assay.

Methods
Experimental setup and laboratory analyses
A sample of sandy forest soil (moisture content less than 5% and maximal water holding capacity approx. 0.6 g/ g dry soil) was collected from the Mt. Barker area (south-west of WA) and stored at between 15 and 25^0C for 8 weeks. To test the influence of soil amendments on soil respiration, 200 g portions of soil sieved through a < 2 mm mesh were mixed with different amendments and 50 ml water (where appropriate), placed in plastic containers and incubated for 4 weeks in the dark at 25^0C. The amendments used were simple carbon sources (D-glucose and organic acids: succinic, D-galacturonic and salicylic), supplied at 24 mg C/g soil; NPK fertiliser at 2.5 g/kg soil; herbicide (Muron 600) at 220 mg/kg soil; activated charcoal at 1:10 w/w and pine shavings at 1:3 v/v. Subsamples of soil for SIR assays were taken on the day of setup two hours after amendment addition and then on the seventh day of incubation (and after four weeks, data not shown). SIR assays were carried out in microplate format drawing from MicroResp^{TM} approach of Campbell *et. al* (2003). Six substrates were used at 18 mg C/g soil: thiamine, glucose, α-ketoglutaric acid, D-glacaturonic acid, imidazole and succinic acid. Due to low solubility in water, a saturated solution of cinnamic acid (the seventh substrate) was used. Control wells were amended with water only, which provided basal respiration measurement. The detection plate was prepared as recommended by Lalor (2007) except for some minor modifications. The results were expressed as µg CO_2-C/g oven dry soil/hr.

Statistical analyses
T-tests and one-way ANOVA with Dunnett's C test for multiple comparisons (Quinn and Keough 2002) were used to compare differences between treatments, which were considered significant when $p<0.05$. Results of two separate experiments are presented.

Results
A "CO_2 burst" (five-fold increase in respiration as compared to dry soil) was observed two hours after re-wetting of unamended soil, but not after seven days. Of the amendments tested, only succinic acid did not inhibit this "CO_2 burst" (Figure 1a, left panel). During SIR assay two hours after rewetting, three of the seven assay substrates reduced soil respiration in control soil (rewetted without amendments), but their inhibitive effect was not observed after incubation for seven days. D-galacturonic acid inhibited soil respiration in the short term both as an amendment and as an assay substrate in rewetted soil (Figure 1a). For complex soil amendments, fertiliser, herbicide and charcoal inhibited respiration both in the short and long-term with levels closer to those of dry soil. However, pine shavings inhibited then stimulated respiration (in long-term) in a way similar to simple carbon sources (Fig 1 b, left panel).

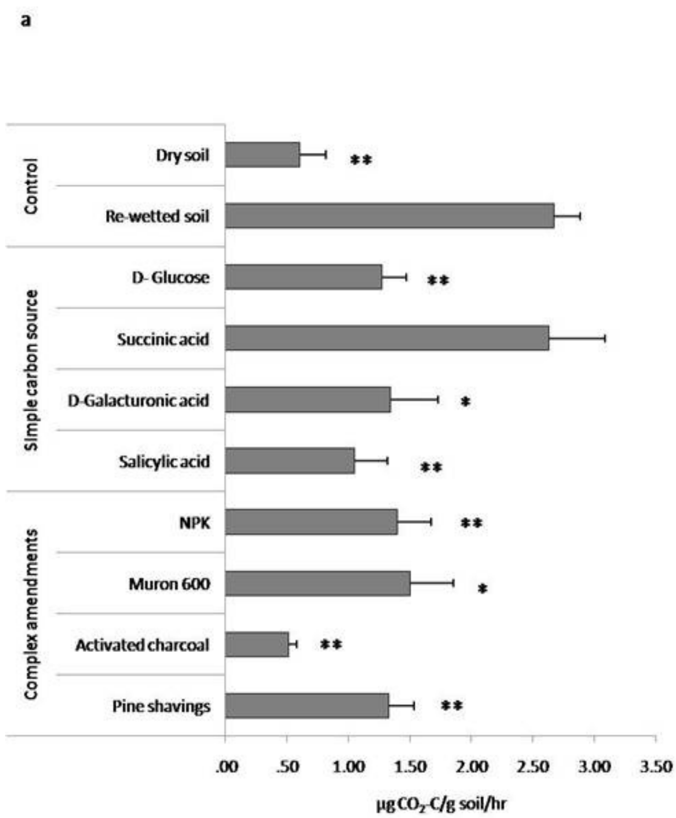
The addition of the amendments not only altered the soil's response to re-wetting, but also its SIR profiles (Figure 1, right panel). Initially, the assay substrates increased respiration in soil amended with NPK and activated charcoal, and to a smaller extent with pine shavings, but not with glucose, succinic acid and herbicide. By the seventh day of incubation, only soils amended with pure water and pine shavings were responsive to only one of the assay substrates (succinic acid and glucose, respectively).

Discussion
Dramatic but short-lived increases in soil respiration after re-wetting, as shown in this study, have been well documented (Fierer and Schimel 2003). It was of concern that sudden rewetting of soil in a CLPP assay could elicit such a response and thus confound the results, "masking" the response to the substrate. However, low respiration level of dry soil (Figure1a, left panel) suggests that small amounts of water used in miniaturised SIR assays fail to elicit "CO_2 burst" and therefore are not likely to interfere with the assay.

Amending soil with simple (SIR substrates) and complex (charcoal and pine shavings) carbon sources prior to SIR assays impaired the soil's ability to respond to rewetting with a "CO_2 burst". These results were inconsistent with the hypothesis of "CO_2 burst" generation posed by Fierer and Schimel (2003) and therefore unexpected. Even more intriguing was the fact that some of the amendments (especially charcoal), despite inhibiting soil's response to rewetting, has altered soil's SIR pattern (Figure 1a, right panel). This suggested the activation of distinct microbial populations in soil. These preliminary results suggest the possibility of using the effect of diminishing of the "CO_2 burst" by substrates, added to soil upon re-wetting, for the purpose of detection of microbial community composition in dry soils (without conditioning or air dried).

Degens (1998) hypothesized that repeated addition of substrates as amendments to soil selects microbial community predisposed to utilisation of these substrates. His observation of additional increases in respiration caused by these substrates used in SIR assay is corroborated by our results (Figure 1b). It is interesting to note that soil amended with pine shavings, despite marked increase in basal respiration by the 7th day of incubation, did not respond to most of the simple carbon sources in respiration assay (until four weeks of incubation, data not shown). It is likely that the complexity of the pine shaving substrate precludes the development of microbial community utilising simple carbon sources until they are released as the pine shavings degrade. Our results suggest that soil rewetting and subsequent incubation with or without amendments stimulate the development of different microbial communities. This is important if we consider that soil conditioning (re-wetting and incubation of soil before microbial analyses) aims at reducing variation in soil microbial analyses. Our results suggest that such a pretreatment may selectively encourage growth of microbial populations (depending of the quality and quantity of microbial substrates available in the soil, as suggested by Degens 1998), therefore becoming a source of additional variation, and thus have important implications for the interpretation of the results of CLPP analyses.

a



Thiamine	Succinic acid	α-ketoglutaric acid	Imidazole	D- Glucose	D-Galacturonic acid	Cinnamic acid
			+			–
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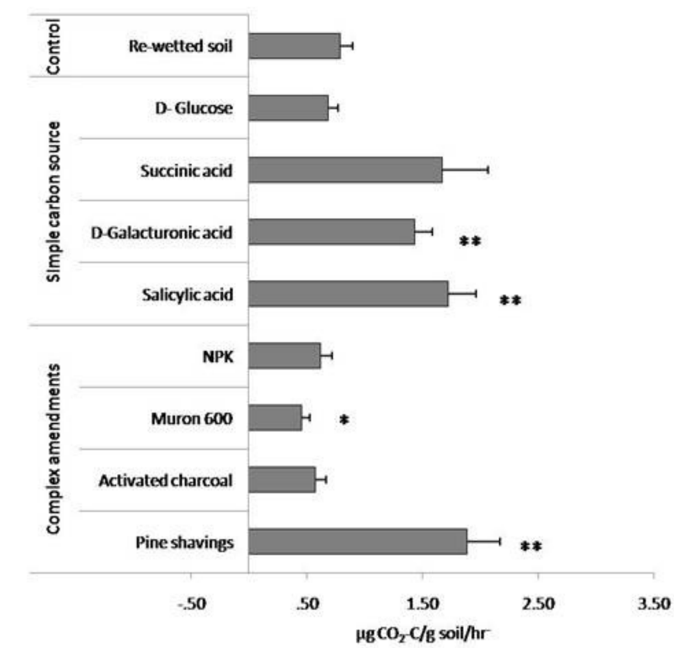
b



Thiamine	Succinic acid	α-ketoglutaric acid	Imidazole	D- Glucose	D-Galacturonic acid	Cinnamic acid
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Figure 1. Basal (left panel) and substrate-induced respiration (right panel) of soil after addition of amendments; (a) 2 hrs and b) 7 days of incubation at 25^{0}C. Error bars denote standard error of the mean. Left panel - difference from control (soil re-wetted with water); * - p<0.05; ** - p<0.01. Right panel - the increase (+) and decrease (-) in respiration as compared to control (water without substrate) in substrate-induced respiration assay are represented by single (p<0.05) or double (p<0.01) symbols.

Conclusion

This study demonstrated that the "CO_2 burst" observed upon rewetting of dry soil can be alleviated by amending soil with a variety of substances; however, the mechanisms behind this are not clear. Taking into account that conditioning can significantly alter soil microbial communities, further investigation of "CO_2

burst inhibition” is warranted for the purpose of developing a method that is suitable for SIR analysis of naturally dry or air-dried soils: one that would not require soil conditioning.

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References

Anderson JPE, Domsch KH (1978) Physiological method for quantitative measurement of microbial biomass in soils. *Soil Biology and Biochemistry* **10**, 215-221.

Campbell CD, Chapman SJ, Cameron CM (2003) A rapid microtiter plate method to measure carbon dioxide evolved from carbon substrate amendments so as to determine the physiological profiles of soil microbial communities by using whole soil. *Applied and Environmental Microbiology* **69**, 3593-3599.

Chapman SJ, Campbell CD, Artz RRE (2007) Assessing CLPPs using MicroReSp (TM) - A comparison with biolog and multi-SIR. *Journal of Soils and Sediments* **7**, 4

Degens BP, Harris JA (1997) Development of a physiological approach to measuring the catabolic diversity of soil microbial communities. *Soil Biology and Biochemistry* **29**, 1309-1320.

Degens BP (1998) Microbial functional diversity can be influenced by the addition of simple organic substrates to soil. *Soil Biology and Biochemistry* **30**, 1981

Degens BP, Schipper LA, Claydon JJ (2000) Irrigation of an allophanic soil with dairy factory effluent for 22 years: responses of nutrient storage and soil biota. *Aust. J. Soil Res.* **38**, 25-35.

Fierer N, Schimel JP (2003) A proposed mechanism for the pulse in carbon dioxide production commonly observed following the rapid rewetting of a dry soil. *Soil Sci. Soc. Am. J.* **67**, 798–805.

Kaufmann K, Chapman SJ, Campbell CD, Harms H, Hohener P (2006) Miniaturized test system for soil respiration induced by volatile pollutants. *Environmental Pollution* **140**, 269-278.

Lalor BM, Cookson WR, Murphy DV (2007) Comparison of two methods that assess soil community level physiological profiles in a forest ecosystem. *Soil Biology and Biochemistry* **39**, 454-462.

Quinn GP, Keough MJ (2002) 'Experimental design and data analysis for biologists' (Cambridge University Press: Cambridge, UK, New York).

The effect of warming on the CO_2 emissions of young and old organic soil from a Sitka spruce plantation.

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Abstract
Under strictly controlled laboratory conditions we investigated the response of soil respiration to increasing temperature. Soil fractions from a Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plantation were sampled to represent "fresh" (i.e. shallower and containing more labile substrates) and "old" (i.e. deeper and presumed to contain more recalcitrant substrates) carbon sources. The soils were incubated at temperatures between 5 - 30 °C, with CO_2 efflux measured using a tunable diode laser. "Fresh" soil showed substantially higher CO_2 effluxes than "old" soil, whilst respiration from "fresh" soils was more sensitive to temperature in the range 5 - 10 °C. After a prolonged (56 day) incubation at 20 °C the response of soils to increasing temperature was re-tested over the same temperature interval. The CO_2 fluxes from both "fresh" and "old" soils were lower than the initial measurements, but the sensitivity to temperature had increased in both "fresh" and "old" soils.

Key Words
Temperature sensitivity, heterotrophic respiration, labile and recalcitrant carbon.

Introduction
Soil organic matter plays a major role in the carbon cycle. The emission of CO_2 from organic matter stored in soils is one of the largest fluxes in the global carbon cycle, so small changes in the size of this flux can have a large effect on atmospheric CO_2 concentrations (Schlesinger and Andrews 2000) and thus constitute a powerful positive feedback to the climate system. Approximately 1500 Gt of organic carbon is stored in the world's soils to a depth of 1 m, with a further 900 Gt between 1-2 m (Kirschbaum 2004). Of particular concern is the fact that soils of high latitudes include many peatlands and other organic soils, and store approximately one third of soil carbon globally (Biasi *et al.* 2005), whilst global warming is expected to be more pronounced at these high latitudes (IPCC 2007). The temperature sensitivity of soil respiration has been a topic of intense debate over recent years, as summarised by Davidson and Janssens (2006). There is evidence to suggest that under higher temperatures soil carbon decomposition will increase, thus resulting in increased CO_2 emissions from heterotrophic respiration (Knorr *et al.* 2005). However there is a contrasting opinion that soil carbon decomposition will be rather insensitive to temperature (Giardina and Ryan 2000), being mostly determined by the supply rate of substrate. Much of the debate considers the temperature sensitivity of the labile versus recalcitrant fractions of the soil carbon. As a large component of SOM is made up of such recalcitrant material, the temperature sensitivity and potential availability as a substrate for microbial respiration of this pool are of acute importance with respect to climate change (Biasi *et al.* 2005).

Materials and methods
Site description and soil sampling
Samples for incubation were collected within Harwood Forest, Northumberland, England (55° 12′ 59" N, 2° 1′ 28" W), a forest consisting of mainly even-aged stands of Sitka spruce (*Picea sitchensis* (Bong.) Carr.). The dominant soil type found in Harwood forest is peaty gley, a soil that is seasonally waterlogged (Zerva *et al.* 2005). Sampled soils were separated into shallow ("fresh") (5 – 15 cm, O_L layer) and deep ("old") (20 – 30 cm, A layer) samples and transported back to the laboratory where they were stored until preparation for incubations began. Average soil C content was 39.1 % in the "fresh" samples, and 21.7 % in the "old" samples, whilst ^{14}C dating of samples aged the "fresh" samples between ~0 – 200 years, and the "old"samples at ~2100 years.

Incubation experiment and respiration measurements
Before the incubation experiment began, all soils were sieved to 4 mm. They were weighed and placed into modified 500 ml Erlenmeyer flasks. Each flask held approximately 500 g of soil at field moisture content. Flasks (n = 6) were then placed into a temperature-controlled waterbath. The initial incubation temperature was 5 °C, and once respiration rates had stabilised at this temperature for ~48 hours the temperature was

increased up to a maximum of 30 °C, before the temperature was decreased back down to 5 °C. At each temperature step, respiration was measured for ~48 hours after rates had stabilised. The total time course of the initial incubation experiment was 22 days. After the initial experiment flasks containing the soils were incubated at 20 °C for 56 days, after which the same incubation from 5 - 30 °C was repeated.
Total heterotrophic soil respiration was determined using a tunable diode laser absorption spectrometer (TGA 100A, Campbell Scientific Inc., Logan, Utah, U.S.A.), using methods described in detail in Bowling *et al.* (2003). Respiration from each flask was calculated using the difference in CO_2 concentrations measured from the reference and sample flasks (containing soil), and the total dry weight of the soil in each flask.

Calculation of Q_{10}
Q_{10} can be defined as the factor by which respiration rate increases for a temperature interval of 10 °C. This relationship between soil respiration and temperature was defined by using the following approach from Fang *et al*. (2005): Mean respiration rates were first fitted with Exponential and Arrhenius models:
$F = ae^{bT}$ (Exponential), where *F* is respiration rate, *a* and *b* are fitted parameters and *T* is the temperature.
$F = ae^{-E/(RT)}$(Arrhenius), where *F* is the respiration rate, *a* is a constant, *E* is the activation energy, *R* is the universal gas constant and *T* is the absolute temperature (K).
Q_{10} was then determined for the models, as well as the actual data using:
$Q_{10} = \frac{F_{T+10}}{F_T}$, where F_T and F_{T+10} are respiration rates at temperatures of *T* and *T*+10.
The relative increase in respiration rate ($(\Delta F/\Delta T)/F_T$) was calculated from the derivative of a fitted polynomial equation, using observed values of temperature (*T*) and respiration rate (*F*), as per Lloyd and Taylor (1994).

Results
Effect of temperature on CO_2 flux from "fresh" and "old" organic matter
During the initial incubation experiment, heterotrophic soil respiration from both the "fresh" and "old" soils increased significantly as the temperature was increased from 5 - 30 °C, with the flux from the "fresh" soils ~2.4 times greater than from the "old" soils (Figure 1). The temperature sensitivity (Q_{10}) of soils during the initial incubation experiment (across the entire measured temperature range) was higher in the "fresh" soils compared to the "old" soils (2.38 and 2.18 respectively), irrespective of the method of obtaining Q_{10}.

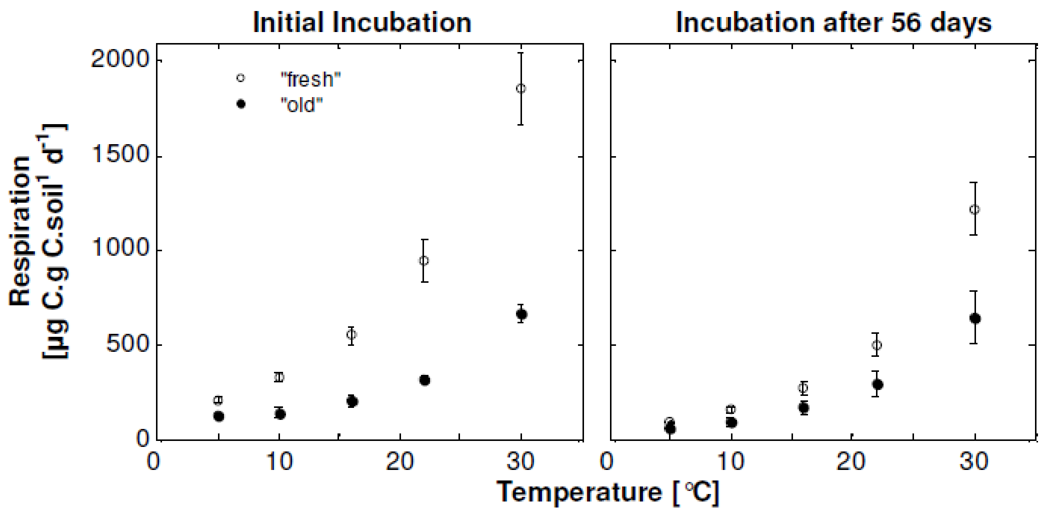

Figure 1. Mean respiration rates of "fresh" and "old" soil organic matter samples incubated from 5 - 30 °C. Initial incubation results and incubation results after 56 days at 20 °C are on the left and right panels respectively. Respiration rates are expressed as per mass of carbon, and error bars are one standard error of the mean (n = 3).

Following constant incubation at 20 °C for 56 days, heterotrophic soil respiration from both "fresh" and "old" soils still responded significantly to increasing temperature, however respiration had decreased in the "fresh" and "old" soils compared to the initial incubation experiment by factors of ~2 and ~1.5 respectively. Fluxes from the "fresh" soils were still significantly higher than the "old" soils although this difference was smaller than during the initial incubation experiment (Figure 1). The measured Q_{10} across the entire temperature range increased after incubation at 20 °C. The Q_{10} of the "fresh" samples was still higher than the "old" (2.77 and 2.51 respectively), however both samples had higher Q_{10} values than that of the initial experiment.

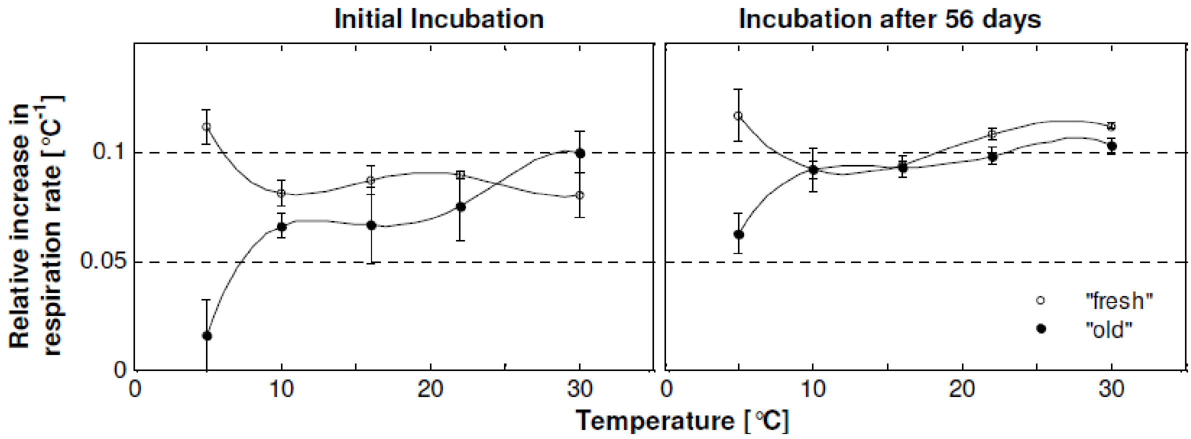

Figure 2. The relative sensitivity of soil respiration to changes in soil temperature, during the initial incubation and incubation after 56 days at 20 °C, calculated using rates adjusted for percentage carbon and bulk density. Smoothed curves have been fitted to values calculated as the derivative of the polynomial fit (see methods), and error bars are one standard error of the mean (n = 3).

To explore the temperature sensitivity of respiration, it is widely acknowledged that the Q_{10} is not a very precise parameter as it averages across a broad range of temperatures. We therefore used the relative increase in respiration, defined by Lloyd and Taylor (1994). During the initial incubation it showed a significant difference between "fresh" and "old" samples at 5 °C ($p < 0.01$), and a significant response to temperature between 5 - 10 °C ($p < 0.01$). After the initial decrease from the "fresh" samples, both samples showed a slight increase in the relative increase in respiration rate in the range 10 - 30 °C (Figure 2). Following incubation at 20 °C for 56 days, the relative increase in respiration rate showed a significant difference between "fresh" and "old" samples at 5 °C ($p < 0.01$), and a significant response to temperature between 5 - 10 °C ($p < 0.01$)(Figure 2). The relative increase in respiration however remained relatively constant for the "fresh" samples, whilst the "old" samples showed an increase with temperature.

Discussion

Respiration after initial and 56 day incubations

The effect of temperature on soil respiration from both the "fresh" and the "old" samples was clearly apparent, with CO_2 flux showing a near-exponential increase with temperature during both the initial incubation, and incubation after 56 days at 20 °C. This relationship was first described by Lundegårdh (1927) and has since been studied and quantified for various soil types from different environments (Kirschbaum 1995). Raw respiration rates measured in the present study were comparable to those from similar studies (Andrews *et al.* 2000; Fang *et al.* 2005). Respiration from the "old" samples was significantly lower than the "fresh" samples. This can be explained by the presence of a high proportion of recalcitrant carbon in the "old" samples. It has been shown that stores of carbon at depth are usually more resistant to decomposition by soil microbes due to their inherent physical properties and chemical constituents (Fierer *et al.* 2003), and recalcitrant soil fractions enriched with resistant alkyl carbon structures increase with soil depth and age (Lorenz *et al.* 2007). Following incubation at 20 °C for 56 days, respiration rates had dropped in both the "fresh" and "old" samples. There was however a much more substantial drop in the "fresh" samples. This is in agreement with studies that have shown that there is a decline in soil respiration rate as incubation time increases (Winkler *et al.* 1996; Reichstein *et al.* 2000; Fang *et al.* 2005). It has been shown that declines such as this are due to a depletion of the most labile substrates, and are greater at higher temperatures (Grisi *et al.* 1998; Fang *et al.* 2005). Given the assumption that the "fresh" samples contained more labile carbon, mineralization of this carbon after the prolonged incubation at 20 °C appears to be responsible for the significant decline in respiration from the "fresh" samples.

Temperature sensitivity of "fresh" and "old" samples

The Q_{10} data from the incubations show that the temperature sensitivity of soil respiration was higher in the "fresh" compared to the "old" samples, using the observed as well as modelled data. After incubation for 56 days at 20 °C, Q_{10} increased for both the "fresh" and "old" samples. Fang *et al.* (2005) hypothesised that Q_{10} values should decrease after a long incubation if the recalcitrant carbon was unresponsive to temperature variations, with a more consistent Q_{10} suggesting that the temperature dependence of recalcitrant carbon is similar to that of labile carbon. Our results support the latter view, with the temperature sensitivity of both "fresh" and "young" being very similar after incubation for 56 days at 20 °C. The relative increase in respiration rate is a term first introduced by Lloyd and Taylor (1994). It expresses the decline in carbon per unit of carbon in the sample. In the present data, the term was significantly higher in the "fresh" samples compared to the "old" samples, and especially so in the range 5 - 10 °C. This has large implications for the fate of labile soil carbon from coniferous forests in temperate climates, given that 5 - 10 °C is a very frequent temperature range. However at higher temperatures the relative sensitivity of the fresh soil samples remained more or less stable, whilst the sensitivity of the old samples increased with temperature up to 30 °C. A similar pattern was evident following the 56 day incubation at 20 °C. However the relative temperature sensitivity for both the "fresh" and the "old" samples was higher than during the initial incubation. Assuming that a large proportion of the labile carbon substrates had been mineralized during the 56 day incubation, this result suggests that the recalcitrant carbon is more responsive to temperature than the labile carbon, a result supported by Fierer *et al*. (2003), however opposed by others (Giardina and Ryan 2000; Thornley and Cannell 2001). Our results support the view that labile and recalcitrant carbon (corresponding to "fresh" and "old" carbon) respond similarly to warming, but after 56 days of incubation, indications suggest that recalcitrant fractions could actually be more sensitive to mineralization, particularly at higher temperatures. The implications of this result are of great importance to the understanding and prediction of the carbon cycle response to climate change in coniferous forests.

References

Andrews JA, Matamala R, Westover KM, Schlesinger WH (2000) Temperature effects on the diversity of soil heterotrophs and the $\delta^{13}C$ of soil-respired CO_2. *Soil Biology and Biochemistry* **32**, 699-706.

Biasi C, Rusalimova O, Meyer H, Kaiser C, Wanek W, Barsukov P, Junger H, Richter A (2005) Temperature-dependant shift from labile to recalcitrant carbon sources of arctic heterotrophs. *Rapid Communications in Mass Spectrometry* **19**, 1401-1408.

Bowling DR, Sargent SD, Tanner BD, Ehleringer JR (2003) Tunable diode laser absorption spectroscopy for ecosystem–atmosphere CO_2 isotopic exchange studies. *Agricultural and Forest Meteorology* **118**, 1-19.

Davidson EA, Janssens IA (2006) Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature* **440**, 165-173.

Fang C, Smith P, Moncrieff JB (2005) Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature* **433**, 57–59.

Fierer N, Allen AS, Schimel JP, Holden PA (2003) Controls on microbial CO_2 production: a comparision of surface and subsurface soil horizons. *Global Change Biology* **9**, 1322-1332.

Giardina C, Ryan M (2000) Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature. *Nature* **404**, 858-861.

Grisi B, Grace C, Brookes PC, Benedetti A, Dell'abate MT (1998) Temperature effects on organic matter and microbial biomass dynamics in temperate and tropical soils. *Soil Biology and Biochemistry* **30**, 1309-1315.

Kirschbaum MUF (1995) The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. *Soil Biology and Biochemistry* **27**, 753-760.

Kirschbaum MUF (2004) Soil respiration under prolonged soil warming: are rate reductions caused by acclimation or substrate loss? *Global Change Biology* **10**, 1870-1877.

Knorr W, Prentice IC, House JI, Holland EA (2005) Long-term sensitivity of soil carbon turnover to warming. *Nature* **433**, 298-301.

Lloyd J, Taylor JA (1994) On the temperature dependence of soil respiration. *Functional Ecology* **8**, 315 – 323.

Lorenz K, Lal R, Preston CM, Nierop KGJ (2007) Strengthening the soil organic carbon pool by increasing contributions from recalcitrant aliphatic bio(macro)molecules. *Geoderma* **142**, 1-10.

Lundegårdh H (1927) Carbon dioxide evolution of soil and crop growth. *Soil Science* **23**, 417-453.

Reichstein M, Bednorz F, Broll G, Kätterer T (2000) Temperature dependence of carbon mineralisation: conclusions from a long-term incubation of subalpine soil samples. *Soil Biology and Biochemistry* **32**, 947-958.

Schlesinger WH, Andrews JA (2000) Soil respiration and the global carbon cycle. *Biogeochemistry* **48**, 7-20.

Winkler JP, Cherry RS, Schlesinger WH (1996) The Q_{10} relationship of microbial respiration in a temperate forest soil. *Soil Biology and Biochemistry* **28**, 1067-1072.

Zerva A, Ball T, Smith KA, Mencuccini M (2005) Soil carbon dynamics in a Sitka spruce (*Picea sitchensis* (Bong.) Carr.) chronosequence on a peaty gley. *Forest Ecology and Management* **205**, 227-240.

The effect of wood ants (*Formica s. str.*) on soil chemical and microbiological properties

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Abstract
The wood ants are very important for boreal forest ecosystems. They substantially affect soil properties, both in their nests and in the nest surroundings. In this study we focused especially on changes in soil pH and activity of microorganisms. Samples were taken from eight ant nests in each of the two types of forest, both in eastern Finland. Samples were taken at four sampling locations, i. e., from the bottom of the nest, the top, the rim and the control (> 3m from each nest). Soil respiration, pH, water content and organic matter content were measured. Soil respiration was higher in ant nests, although there was lower moisture. This could be explained by the import of easily available substances in prey and honeydew into the nest. pH values were higher in ant nests. This is most probably caused by enhanced contents of basic cations that are usually found in ant nests. Differences in organic matter content were found between individual nest sampling locations, which could be caused by differences in ant nest construction. The differences between the two types of forest show that the influence of very similar ant species differs in dependence on environmental conditions.

Key Words
Birch forest, pine forest, humus layer, soil mineral layer, *Formica aquilonia*, *Formica rufa*.

Introduction
Wood ants (*Formica s. str.*, Hymenoptera: Formicidae) are very important for temperate and boreal forest ecosystems because they affect many soil properties (Dlusskij 1967; Frouz and Jilkova 2008). They are considered to be ecosystem engineers (Jones *et al.* 1994; Jouquet *et al.* 2006). They affect soil pH in their nests and their surroundings by mixing soil layers and bringing food into their nests (Frouz *et al.* 2003). Through their activities they maintain stable temperature regime (Frouz and Finer 2007) and they also affect the composition of soil microorganisms in their nests (Czerwiński *et al.* 1971; Petal *et al.* 2003). Through these effects, soil respiration in ant nests could be different from that of the nest surroundings. In this study we focused especially on differences in soil respiration, soil pH, water content and organic matter content between individual sampling locations in ant nests and between ant nests and their surroundings.

Methods
Sampling sites and study design
This study was conducted in two types of forest in eastern Finland in August 2009. The first type was a birch (*Betula spp.*) dominated forest and the second type was a pine (*Pinus sylvestris*) dominated forest. We selected 8 ant nests in each type of forest (a birch forest – *Formica aquilonia*, a pine forest – *Formica rufa*). Soil samples were taken at four sampling locations at each nest, i.e., from the top of the nest, the bottom, the rim, and the control (>3 m away of the nest). Samples were taken from the humus layer and from the soil mineral layer at control locations. Soil samples were then stored in a refrigerator for measuring soil respiration and water content, and then they were dried at 70°C for measuring pH and organic matter content.

Analyses of soil samples
For soil respiration, 10g of soil sample was incubated in a 100ml bottle for two days with 3 mL of 1N NaOH at 25°C and then NaOH was titrated with HCl (Page 1982). Water content was determined after drying for 12h at 105°C. Soil pH was measured in a 1:5 soil: water suspension by glass electrode. Organic matter content was determined based on ignition loss after 5 hours in 600°C.

Statistics
The data were analysed using Statistica 8.0. Split-plot design ANOVA with the nest as a random factor was used for determination of effects of the forest type and sampling location on each soil property. Post-hoc test (Tukey HSD) was used to determine significant differences between individual sampling locations.

Results

The type of forest has significant effect on soil pH ($F_{1,56}$=7.62, p<0.05) and water content ($F_{1,56}$=14.59, p<0.05), whereas sampling location has significant effect on all measured soil properties, i.e., soil respiration ($F_{4,56}$=27.37, p<0.05), soil pH ($F_{4,56}$=68.23, p<0.05), water content ($F_{4,56}$=94.60, p<0.05), and organic matter content ($F_{4,56}$=165.34, p<0.05) (Table 1). Interaction between the type of forest and sampling location has also significant effect on all measured soil properties, i.e., soil respiration ($F_{4,56}$=7.86, p<0.05), soil pH ($F_{4,56}$=6.21, p<0.05), water content ($F_{4,56}$=7.21, p<0.05), and organic matter content ($F_{4,56}$=6.50, p<0.05) (Table 1).

Table 1. Influence of a type of forest, a sampling location and interaction between these two factors on soil respiration, pH, water content (WC), and organic matter content (OMC) of 80 samples taken from 16 ant nests in total. Significant interactions <0.05, non-significant interactions ns. Split-plot design ANOVA.

	Respiration	pH	WC	OMC
(1) type of forest	ns	$F_{1,56}$=7.62 <0.05	$F_{1,56}$=14.59 <0.05	ns
(2) sampling location	$F_{4,56}$=27.37 <0.05	$F_{4,56}$=68.23 <0.05	$F_{4,56}$=94.60 <0.05	$F_{4,56}$=165.34 <0.05
(1x2) interaction	$F_{4,56}$=7.86 <0.05	$F_{4,56}$=6.21 <0.05	$F_{4,56}$=7.21 <0.05	$F_{4,56}$=6.50 <0.05

In the birch forest, soil respiration in ant nests was higher in comparison with the control and significantly differed from that of the soil mineral layer, but not from that of the humus layer, except of the top of ant nests (Figure 1a). Soil respiration was the highest at the top of ant nests and significantly differed from that of the bottom but not the rim of ant nests. In the pine forest, soil respiration in ant nests was also higher in comparison to the control, but significantly differed from that of the humus and the soil mineral layer only at the bottom and the rim of ant nests (Figure 1a). There were no significant differences between the top, the bottom, and the rim of ant nests. Between the two types of forest, there was a significant difference in soil respiration only between the tops of ant nests.

Soil pH in ant nests in the birch forest differed from that of the humus layer, with higher values in ant nests, but not from the soil mineral layer (Figure 1b). There were no differences in pH between individual sampling locations in ant nests, but there was a difference in pH between the humus and the soil mineral layer. In the pine forest, soil pH in ant nests differed from that of the humus layer, with higher values in ant nests, but not from the soil mineral layer, except of the top of ant nests (Figure 1b). There were also differences between the top and the bottom of ant nests, with higher values at the bottom, and the humus and the soil mineral layer. Between the two types of forest, there were no significant differences in pH between individual sampling locations.

In the birch forest, water content in ant nests was significantly lower than that of the humus layer, but does not differed from that of the soil mineral layer, except of the top of ant nests (Figure 1c). There were differences between the top of ant nests and the bottom and the rim, with higher values at the top. There was also a significant difference between the humus and the soil mineral layer, with higher values in the humus layer. In the pine forest, there were only differences in water content between ant nests and the soil mineral layer and the humus layer, with higher values in the humus layer (Figure 1c). Between the two types of forest, there was only a significant difference between the tops of ant nests.

Organic matter content in ant nests in the birch forest significantly differed from that of the soil mineral layer and that of the humus layer, except of the top of ant nests (Figure 1d). In ant nests, there were differences between all sampling locations, with the highest values at the top of ant nests, and there was also a difference between the humus and the soil mineral layer, with higher values in the humus layer. In the pine forest, organic matter content in ant nests significantly differed from that of the humus layer and that of the soil mineral layer, except of the rim of ant nests (Figure 1d). In ant nests, there were differences only between the top of ant nests and the bottom and the rim, with higher values at the top. There was a difference between the humus and the soil mineral layer, with higher values in the humus layer. Between the two types of forest, there were significant differences between the bottoms of ant nests and the humus layer.

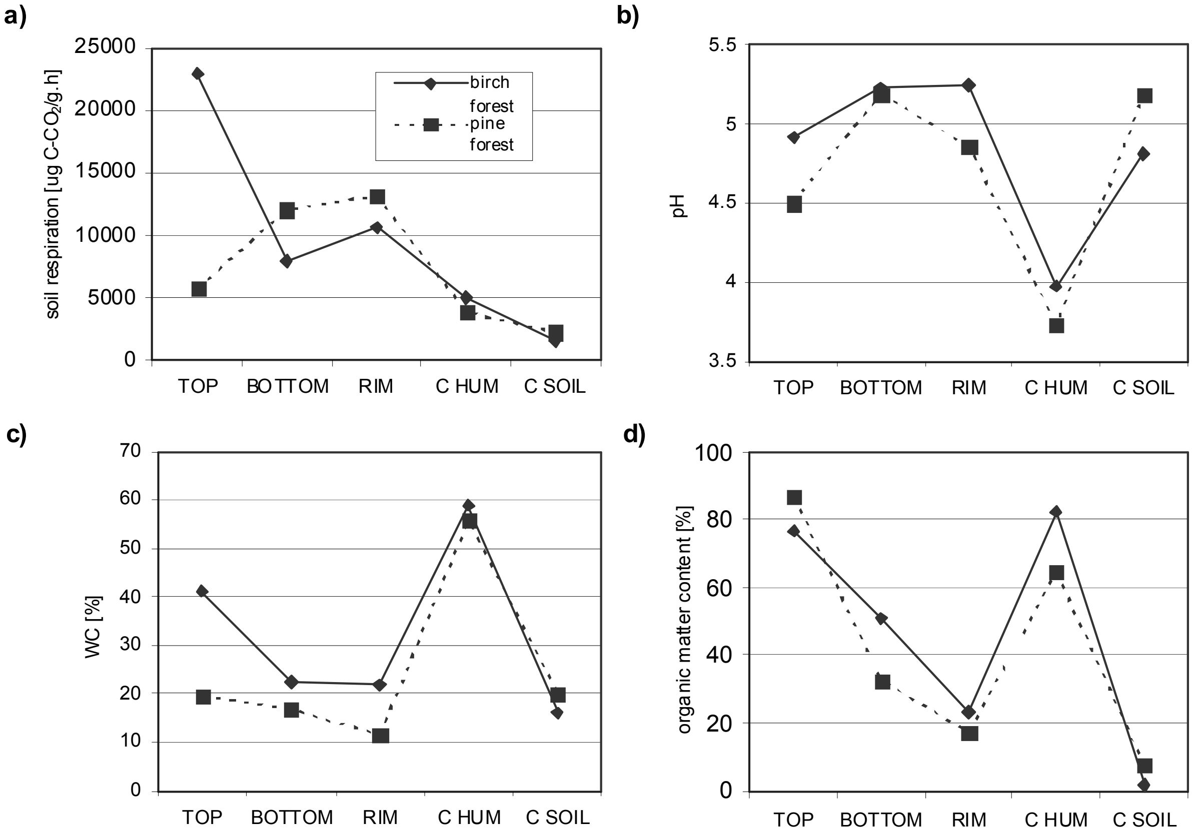

Figure 1. The effect of sampling locations on a) soil respiration, b) soil pH, c) water content, and d) organic matter content in a birch and a pine forest. TOP, BOTTOM, and RIM mean sampling locations in ant nests, C HUM and C SOIL mean control sampling locations in the humus and the soil mineral layer. Data are based on 80 soil samples in total (split-plot design ANOVA).

Discussion

Soil respiration quite differed between the two types of forest. In the birch forest, the highest respiration rates were found at the top of ant nests, which values differed significantly from that of the humus layer. In the pine forest, the highest respiration rates were found at the bottom and the rim of ant nests. These differences may be caused by differences in soil pH, water content and the quality of organic matter content. These properties are known to be responsible for the changes in soil respiration (Amador and Görres 2007; Lenoir *et al.* 2001). The nest respiration strongly depends on nest moisture but here, drier nests had higher respiration rates probably due to the import of easily available substances in prey and honeydew into the nests (Horstmann 1974). Higher respiration rates in ant nests are in agreement with Laakso and Setälä (1998). In that study, ant nests are considered as hot spots for decomposers.

Higher pH values were found in ant nests, especially in comparison to the humus layer. This is not a surprising result given that the forest humus layer is typically highly acidic (Brady and Weil 2001). pH is strongly correlated with organic matter content (Frouz *et al.* 2003). At the top of ant nests, higher pH values were found in comparison to the humus layer, and at the bottom and the rim, higher pH values were found in comparison to the soil mineral layer, although high organic matter content was found in ant nests. These results show that there are also other factors influencing soil pH. One of them could be higher contents of basic cations in ant nests (Frouz *et al.* 2003). In agreement with previous studies, ant nests were drier in comparison to the surroundings of the nests (Dlusskij 1967; Frouz and Jilkova 2008; Jurgensen *et al*. 2008). The highest water contents were found at the tops of ant nests, which is in agreement with Frouz (1996).

The differences in organic matter content between the tops of ant nests and the bottoms and the rims of ant nests could be most probably explained by differences in ant nest construction. The bottom and the rim of an ant nest is built by excavation of the deeper soil profiles that do not contain much organic matter, whereas the top of an ant nests is mainly built of needles and twigs from the nest surroundings (Dlusskij 1967). The differences between the two types of forest show that the influence of even very similar ant species differs in dependence on environmental conditions (Holec 2006)

Aknowledgements
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References

Amador JA, Görres JH (2007) Microbiological characterization of the structures built by earthworms and ants in an agricultural field. *Soil Biology and Biochemistry* **39**, 2070-2077.

Brady NC, Weil RR (1999) 'The Nature and Properties of Soils.' (Prentice-Hall: Upper Saddle River, New Jersey)

Czerwiński Z, Jakubczyk H, Petal J (1971) Influence of ant hills on the meadow soils. *Pedobiologia* **11**, 277-285.

Dlusskij GM (1967) 'Muravji roda *Formica*.' (Nauka: Moskva)

Frouz J (1996) The role of nest moisture in thermoregulation of ant (*Formica polyctena*, Hymenoptera, Formicidae) nests. *Biologia* **51**, 541-547.

Frouz J, Finer L (2007) Diurnal and seasonal fluctuations in wood ant (*Formica polyctena*) nest temperature in two geographically distant populations among a south-north gradient. *Insectes Sociaux* **54**, 251-259.

Frouz J, Jilkova V (2008) The effect of ants on soil properties and processes (Hymenoptera: Formicidae). *Myrmecological News* **11**, 191-199.

Frouz J, Holec M, Kalcik J (2003) The effect of *Lasius niger* (Hymenoptera: Formicidae) ant nest on selected soil chemical properties. *Pedobiologia* **47**, 205-212.

Holec M, Frouz J (2006) The effect of two ant species *Lasius flavus* and *Lasius niger* on soil properties in two contrasting habitats. *European Journal of Soil Biology* **42**, 213-217.

Horstmann K (1974) Untersuchungen über den Nahrungswerb der Waldameisen (*Formica polyctena* Foerster) im Eichenwald. III. Jahresbilanz. *Oecologia* **15**, 187-204.

Jones CG, Lawton JH, Shachak M (1994) Organisms as ecosystem engineers. *Oikos* **69**, 373-386.

Jouquet P, Dauber J, Lagerlöf J, Lavelle P, Lepage M (2006) Soil invertebrates as ecosystem engineers: Intended and accidental effects on soil and feedback loops. *Applied Soil Ecology* **32**, 153-164.

Jurgensen MF, Finer L, Domisch T, Kilpelainen J, Punttila P, Ohashi M, Niemela P, Sundstrom L, Neuvonen S, Risch AC (2008) Organic mound-building ants: their impact on soil properties in temperate and boreal forest. *Journal of Applied Entomology* **132**, 266-275.

Laakso J, Setälä H (1998) Composition and trophic structure of detrital food web in ant nest mounds of Formica aquilonia and in the surrounding forest soil. *Oikos* **81**, 266-278.

Lenoir L, Persson T, Bengtsson J (2001) Wood ant nests as potential hot spots for carbon and nitrogen mineralisation. *Biology and Fertility of Soils* **34**, 235-240.

Page AL (1982) 'Methods of soil analysis. Part 2. Chemical and microbiological properties.' (American Society of Agronomy Inc.: Madison, WI)

Petal J, Chmielewski K, Kusińska A, Kaczorowska R, Stachurski A, Zimka J (2003) Biological and chemical properties of fen soils affected by anthills of *Myrmica spp. Polish Journal of Ecology* **51**, 67-78.

Tree nutrition and chemical properties of a sandy soil in a pine plantation receiving repeated biosolids applications

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Abstract
Biosolids are rich in organic carbon and nutrients and are commonly used as a fertiliser and soil amendment. Since the mid-1990s, a *Pinus radiata* (D. Don) plantation growing on a sandy, low fertility soil at Rabbit Island near Nelson, New Zealand, has received aerobically digested liquid biosolids. An experimental research trial was established on the site in 1997 to investigate the effects of biosolids applications on tree growth, nutrition, and soil quality. Biosolids have been applied to the trial site every three years since 1997, at three application rates: 0 (Control), 300 (Low) and 600 kg N/ha (High). Tree nutrition status is monitored annually. Soil samples were taken in August 2007 to assess the effects of the repeated biosolids application on soil chemical properties. Biosolids application increased N concentration in pine foliage. Forest litter and soil analysis indicates that the High biosolids treatment has significantly increased concentrations of soil available P and organic C, but reduced soil pH. The High biosolids treatment has also increased concentrations of total soil Cu, Pb and Zn, although overall concentrations are considered to be very low for a soil. The Low biosolids treatment had no significant effect on soil chemical properties. Our results show that repeated application of biosolids to a plantation forest can significantly improve tree nutrition and site productivity. However, the biosolids-derived heavy metals are strongly retained by the litter layer. The long term effects of these litter-retained metals need to be evaluated.

Key Words
Sewage sludge, plantation forest, low fertility, soil quality.

Introduction
Using biosolids (i.e., treated sewage sludge) as a fertiliser and soil amendment is one of the most common options for biosolids management (Magesan and Wang 2003). Compared with applying biosolids to agricultural land, forest land application can reduce the risk of contaminants entering the human food chain, and can also increase tree growth and subsequent economic returns (Kimberley *et al.* 2004). The regional wastewater treatment plant in Nelson, New Zealand, originally established in 1983, was upgraded to incorporate the handling of biosolids in 1995/96. After treatment, biosolids from the scheme are applied to a 1000-ha *Pinus radiata* D. Don forest plantation at Rabbit Island near Nelson City. A long-term trial was established in 1997 to monitor the environmental effects of the repeated application of biosolids on the plantation, and to determine sustainable application rates. Since then tree growth and nutrition and wood properties have been assessed along with a number of environmental variables, such as soil and groundwater quality (Wang *et al.* 2004; 2006). The objective of this study was to investigate the effects of repeated applications of biosolids on tree nutrition and soil chemical properties.

Materials and methods
The research trial was established in 1997 in a 6-year-old stand of *Pinus radiata* in the Rabbit Island plantation. The soil consists of coarse coastal dune sands, classified as a sandy raw soil (Hewitt 1998), which provides free rooting access to the shallow groundwater 2.0 to 4.2 m below the surface. Three biosolids treatments were applied in a split-plot, randomised block design with four replicates. The treatments consisted of a Control (no biosolids), a Low treatment (target application of 300 kg N/ha) and a High treatment (at a target rate of 600 kg N/ha). Each main-plot contained three stocking density treatments (subplots) at 300, 450 and 600 stems/ha. There were 36 subplots in total (4 replicates × 3 biosolids rates × 3 stocking densities), each plot measuring 25 m × 25 m, plus 5 m buffer zones, so that the whole site covered an area of approximately 4 ha. The biosolids were applied in October 1997 and reapplied at the same rates to the same plots in November 2000, October 2003, and October 2006. The biosolids contained high concentrations of nitrogen (approximately 10% N with about 40% in ammonium form). Concentrations of contaminants such as pathogens and heavy metals in the biosolids were low and well below the New Zealand

guidelines for land application (NZWWA 2003), and therefore would not limit beneficial use through land application. Details about properties of the biosolids applied and method of application were given by Wang *et al.* (2004).

To assess changes in tree nutrition due to biosolids application, foliage samples (present year's secondary foliage in top third of crown) have been collected from selected trees in each plot annually in summer since 1998. The impact of biosolids applications on soil chemical properties was assessed from samples taken from the litter layer, topsoil (0–0.25 m depth) and subsoil (0.25–0.5 m depth) in August 2007. Samples were taken from all subplots within each biosolids treatment main-plot and bulked, resulting in four replicate samples per biosolids treatment. The foliage and litter were oven-dried (70^{o}C) and ground for chemical analysis. Soil samples were air-dried and ground to pass a 2-mm sieve. Soil pH was measured at a soil:water ratio of 1:2. Total N in soil, tree foliage and understorey samples, and total C in soil were determined by dry combustion using a Leco CNS 2000 machine. Concentrations of soil exchangeable Ca, Mg, K, and Na were measured using the ammonium acetate method (Blakemore *et al.* 1987). Extractable soil P was determined using the Olsen P method. Acid digestion was used to extract heavy metals in biosolids and soil samples (ASTM International 1999). Flame atomic absorption spectrometry was used to determine As, Cd, Cr, Cu, Pb, Ni, and Zn in the acid digestion and groundwater samples. Mercury was analysed using cold vapour atomic absorption spectrometry (APHA 1995). Foliage and litter samples were digested with concentrated HNO_3/H_2O_2, and concentration of nutrients and heavy metals in the digest were determined using the inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer Optima 3000DV).

Analysis of variance (ANOVA) and least significant difference (LSD) tests were used to determine the statistical significance of the biosolids treatment effects on tree nutrition over time and soil properties using the SAS/STAT Version [9] GLM procedure.

Results and discussion

Effect of biosolids application on tree nutrition

Annual foliage analyses have shown that foliar concentrations of all nutrients except N have remained in the "satisfactory" range of tree nutrition and indicate that none of these nutrients are limiting tree growth (Will 1985). However, they have consistently shown that natural soil N supply in the Rabbit Island *P. radiata* forest is low, with foliar N concentration of the Control treatment averaging 1.2% N since monitoring began (Figure 1), well under the 1.5% N, threshold below which *P. radiata* may benefit from nitrogen fertiliser (Will 1985). Both biosolids treatments have produced significant ($P < 0.05$) elevations in foliar N with the Low treatment averaging 1.4% N and the High treatment 1.5% N.

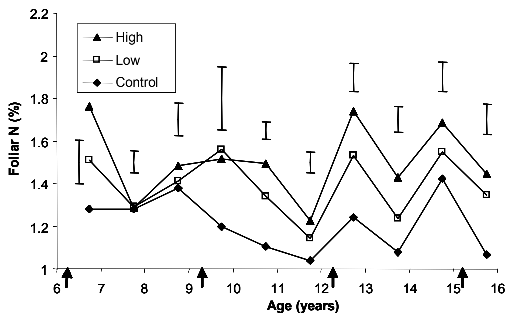

Figure 1. Effect of biosolids application on concentrations of nitrogen in foliage. Arrows indicate time of biosolids application. Error bars show least significant differences (*P* = 0.05) and can be used to determine the significance of treatment differences.

Effect of biosolids application on forest litter and soil chemistry

Analysis of the forest litter layer samples collected in 2007 show that both of the biosolids treatments significantly ($P < 0.05$) increased C/N ratios and concentrations of total P and Mg (Table 1). The High biosolids treatment significantly ($P < 0.05$) increased concentrations of total N and Fe, whereas the Low biosolids treatment significantly ($P < 0.05$) increased concentrations of total Na and B in the litter. Litter Mn concentration in the High biosolids treatment was significantly ($P < 0.05$) lower than the Control (Table 1). These changes in litter elemental concentration can be attributed to the initial litter chemical composition and retention of biosolids-derived elements. For example, significantly lower Mn concentrations in foliage samples were observed (Wang *et al.* 2004).

Table 1. Effect of biosolids application on litter chemical properties (sampled in August 2007)*

Treatment	C	N	P	K	Ca	Mg	Na	C/N	B	Mn	Fe
				%						mg/kg	
Control	47.0 a	1.02 a	0.055 a	0.079 a	0.36 a	0.17 a	0.029 a	47 a	10 a	445 a	1100 a
Low	44.0 a	1.28 ab	0.069 b	0.097 a	0.41 a	0.19 b	0.043 b	35 b	14 b	375 ab	1665 ab
High	47.9 a	1.47 b	0.071 b	0.079 a	0.40 a	0.19 b	0.038 ab	34 b	11 ab	318 b	2313 b

*Values within a column followed by the same letter do not differ significantly (LSD test, $P = 0.05$; number of replications per treatment = 4).

Analysis of soil samples show significantly ($P < 0.05$) increased soil organic C and available P (Olsen P), and reduced soil pH in the top soil layer (0–0.25 m) in the High treatment. Biosolids treatments had no significant effect on concentrations of total soil N and exchangeable Mg, K, and Na, but significantly increased soil exchangeable Ca in the Low treatment (Table 2). The significantly ($P < 0.05$) higher soil P concentration in the 0-0.25 m and 0.25–0.5 m layers (Table 2) suggests that the High rate biosolids application has not only resulted in accumulation in the topsoil but also caused some P movement down the soil profile. This agrees with findings of Lu and O'Connor (2001) who reported that biosolids-derived P may be susceptible to leaching through sandy soils, due to the low soil P-sorbing capacity. Biosolids treatments significantly ($P < 0.05$) increased the soil C/N ratios in the 0.25-0.5 m layer. This was due to the increase of total C with biosolids treatments, which may be caused by the downward movement of organic C in the soil profile. Analysis of deeper soil layers has been proposed to verify the P and organic C movement in the soil profile.

Table 2. Effect of biosolids application on soil chemical properties (sampled in August 2007)*

Depth	Treatment	pH	C	N	C/N	Olsen P	K	Ca	Mg	Na
			%			mg/kg		cmol$_c$/kg		
	Control	5.30 a	0.55 a	0.03 a	18.4 a	29.1 a	0.09 a	0.95 a	1.11 a	0.07 a
0-0.25m	Low	5.18 ab	0.74 ab	0.04 a	18.8 a	36.7 a	0.10 a	1.05 b	1.13 a	0.08 a
	High	4.93 b	0.89 b	0.05 a	20.3 a	56.3 b	0.11 a	1.03 ab	0.99 a	0.08 a
	Control	5.80 a	0.25 a	0.03 a	8.9 a	21.5 a	0.07 a	0.75 a	1.02 a	0.04 a
0.25-0.5m	Low	5.70 a	0.26 a	0.03 a	9.4 b	21.5 a	0.07 a	0.75 a	1.06 a	0.07 a
	High	5.33 a	0.36 a	0.03 a	11.8 b	32.8 b	0.08 a	0.68 a	0.95 a	0.07 a

*For each depth, values within a column followed by the same letter do not differ significantly (LSD test, $P = 0.05$; number of replications per treatment = 4).

Biosolids applications significantly ($P < 0.05$) increased total concentrations of all eight heavy metals measured in the litter layer, except for Pb and Ni in the Low treatment (Table 3), which implies that a large proportion of the biosolids-derived metals are strongly retained by the litter layer. High metal retention capacity by forest litter was also reported by McLaren *et al.* (2007) who found that concentration of heavy metals in the litter layer was greatly elevated even a few years after biosolids were applied.

Table 3. Effect of biosolids application on concentrations of heavy metals in litter and soil (sampled in August 2007)*.

Depth	Treatment	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
					mg/kg				
	Control	0.6 a	0.02 a	2.5 a	4.5 a	3.4 a	0.05 a	4.0 a	19.0 a
Litter	Low	0.8 b	0.09 b	5.2 b	13.3 b	4.8 ab	0.08 b	5.5 ab	37.5 b
	High	1.2 b	0.22 c	10.5 c	61.3 c	8.8 b	0.16 c	11.9 b	69.8 c
	Control	2.6 a	<0.05 a	21.5 a	3.9 a	3.9 a	<0.05 a	28.5 a	26.0 a
0-0.25m	Low	2.3 a	<0.05 a	20.8 a	4.7 ab	4.0 ab	<0.05 a	27.8 a	26.5 a
	High	2.1 a	<0.05 a	21.6 a	6.3 b	4.3 b	<0.05 a	25.8 a	30.5 b
	Control	2.9 a	<0.05 a	24.3 a	4.3 a	4.0 a	<0.05 a	43.8 a	27.3 a
0.25-0.5m	Low	3.0 a	<0.05 a	23.8 a	4.5 ab	4.0 a	<0.05 a	41.8 a	27.3 a
	High	3.5 a	<0.05 a	24.8 a	4.9 b	4.0 a	<0.05 a	44.5 a	29.3 a

*For each depth, values within a column followed by the same letter do not differ significantly (LSD test, p=0.05; number of replications per treatment=4).

Although concentrations of heavy metals in underlying soils showed less obvious changes in response to biosolids application than in the litter layer, the High biosolids treatment had significantly ($P < 0.05$)

increased concentrations of soil Pb and Zn in the 0–0.25 m layer, and significantly increased soil Cu concentrations in both 0–0.25 m and 0.25–0.5 m layers (Table 3). The increased Cu concentration in soils receiving biosolids applications (Table 3) did not result in increased *P. radiata* foliage Cu concentration (data not shown), indicating a low bioavailability of the biosolids-derived Cu. The relatively higher concentrations of Cr and Ni in the 0.25-0.5 m layer than in the 0-0.25 m layer were due to the natural soil conditions, and were not affected by the biosolids applications. Generally, heavy metal concentrations (Table 3), with or without biosolids application, were low and well below the soil contaminant limits defined by the guidelines for the safe application of biosolids to land in New Zealand (NZWWA 2003). Overall, repeated application of biosolids improved soil fertility and appeared to have no significant detrimental effect on soil quality at Rabbit Island.

Conclusions

Repeated application of biosolids to a *P. radiata* plantation on a low fertility sandy soil on Rabbit Island has significantly enhanced N supply to meet tree growth demands. The High biosolids treatment significantly increased concentrations of soil available P and organic C, but it resulted in a reduced soil pH. Although the High biosolids treatment increased the concentration of total soil Cu, Pb and Zn, overall concentrations of these heavy metals are considered to be very low for a soil. The Low biosolids treatment had no significant effect on soil chemistry. However, the biosolids-derived heavy metals are strongly retained by the litter layer. The long term effects of these litter-retained metals will be further assessed in future studies.

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References

APHA (1995) 'Standard Methods for the Examination of Water and Wastewater, 19th Edition'. (American Public Health Association: Washington DC).

ASTM International (1999) 'ASTM Standard D 3974-81. Standard practices for extraction of trace elements from sediments'. (American Society for Testing and Materials: Philadelphia).

Blakemore LC, Searle PL, Daly BK (1987) 'Methods for chemical analysis of soils'. New Zealand Soil Bureau Scientific Report 80. (DSIR: Lower Hutt).

Hewitt AE (1998) 'New Zealand soil classification'. 2nd edition. Landcare Research Science Series No 1, (Manaaki Whenua Press: Lincoln).

Kimberley MO, Wang H, Wilks PJ, Fisher CR, Magesan GN (2004) Economic analysis of growth response from a pine plantation forest applied with biosolids. *Forest Ecology and Management* **189**, 345-351.

Lu P, O'Connor GA (2001) Biosolids effects on P retention and release in some sandy Florida soils. *Journal of Environmental Quality* **30**, 1059-1063.

Magesan GN, Wang H (2003) Application of municipal and industrial residuals in New Zealand forests: an overview. *Australian Journal of Soil Research* **41**, 557-569.

McLaren, RG, Clucas LM, Speir,TM, Schaik, AP (2007) Distribution and movement of nutrients and metals in a *Pinus radiata* forest soil following application of biosolids. *Environmental Pollution* **147**, 32-40.

NZWWA (2003) 'Guidelines for the safe application of biosolids to land in New Zealand'. (New Zealand Water and Wastes Association: Wellington).

Wang H, Kimberley MO, Magesan GN, McKinley RB, Lee JR, Lavery JM, Hodgkins PDF, Payn TW, Wilks PJ, Fisher CR, McConchie DL (2006) Mid-rotation effects of biosolids application on tree growth and wood properties in a Pinus radiata plantation. *Canadian Journal of Forest Research* **36**, 1921-1930.

Wang H, Magesan GN, Kimberley MO, Payn TW, Wilks PJ, Fisher CR (2004) Environmental and nutritional responses of a *Pinus radiata* plantation to biosolids application. *Plant and Soil* **267**, 255-262.

Will GM (1985) 'Nutrient deficiencies and fertiliser use in New Zealand exotic forests'. FRI Bulletin No. 97. (New Zealand Forest Service: Rotorua).

Using the multivariate data set of SOM quality to assess the management-induced changes in forest soils

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Abstract
Successful soil organic matter (SOM) quality assessment is needed to improve our ability to manage forest soils sustainably. Our objective was to use a multivariate data set to determine whether the land-use conversion from native forest (NF) to hoop pine plantation and the following rotation and site preparation practices had altered SOM quality at three adjacent sites of NF, first (1R) and second rotation (2R, including tree planting row (2R-T) and windrow of harvest residues (2R-W)) of hoop pine plantations in southeast Queensland, Australia. Knowledge of PCA based on the refined set of 41 SOM quantitative and qualitative parameters identified that principal component 1 (PC1), which explained 55.7% of the total variance, was most responsible for the management induced changes in soil processes. This was reflected by the dynamics of SOM regarding the aspects of total stock, soil basal and substrate induced respirations, gross and net N mineralization and nitrification, and microbial biomass, microbial diversity of C utilization patterns. Further, the macroaggregates ($F_{250\text{-}2000\mu m}$) and the C/N ratio of acid extracts of SOM physical fractions, which represented the most informative and unique variables loading on PC1, might be the most promising physical and chemical measures for SOM quality assessment of land use and management impacts in subtropical Australian forests.

Key Words
SOM quality assessment, land use and management impacts, physical fractions, CPMAS ^{13}C NMR, sequential hot water extraction and acid hydrolysis, forest.

Introduction
Three well-studied adjacent NF, 1R and 2R hoop pine plantation forest sites that exhibited different responses in whole soil chemical and biological processes to different forest types, rotation practices and residue management were selected as the study area. Our objectives were (1) to investigate the complex interactions between forest management practices and SOM quality, and (2) to screen and explore the most informative and unique SOM quality parameters which underpin the changes of soil chemical and biological processes induced by forest management. We hypothesized that the chemical analyses on physical soil separates could reveal more meaningful differences in soil C and N physical protection and biochemical recalcitrance in response to land use and management changes. To test these hypotheses, we carried out a combination of physical (wet-sieving and density) fractionation and structural chemical analyses (CPMAS ^{13}C NMR spectroscopy and sequential hot water extraction and acid hydrolysis) of the fractions obtained.

Methods
Site description
The NF and hoop pine plantation study sites were located in Yarraman State Forest, southeast Queensland, Australia. The 1R plantation was converted from NF in 1952. The 2R hoop pine was planted in 2000 after the clearcut harvest of part of the 1R plantation in 1999. Post harvest residues from the 1R plantation were formed into windrows approximately 6 m apart, and areas between windrows were then used as tree-planting rows for the 2R plantation. Hence, the three NF, 1R and 2R hoop pine plantation areas are adjacent to each other, and the 2R plantation area was divided into the following two treatments based on the residue management practices, (1) tree planting row (2R-T) and (2) windrow of harvest residues (2R-W).

Identification of the quantitative and qualitative parameters of SOM fractions
Cross-polarization magic angle spinning ^{13}C nuclear magnetic resonance (CPMAS ^{13}C NMR) spectroscopy and sequential hot water and acid hydrolysis were conducted on SOM fractions separated by wet-sieving and density fractionation procedures to characterize SOM quantitative and qualitative relevant parameters, including carbon (C) functional groups, C and nitrogen (N) contents, C/N ratios, and C and N recalcitrant indices.

Results

Site-based differences in SOM quality: ANOVA and PCA results for fraction C pool, N pool and C/N ratio parameters

The minimum data set of overall SOM quality (constituted by 41 variables that retained from the ANOVA and PCA results of individual categories, data not shown) was assessed to screen for the most informative and unique variables that reflected the SOM quality changes induced by land use and management among the tested forest sites. In general, there were three significant PCs that together explained more than 81% of the total variance. PC1, which accounted for 55.7% of the total variance, contrasted $F_{250\text{-}2000\mu m}$ that showed relatively high loadings from other SOM fractions. The 27 parameters had significant loadings on PC1, among which the highest negatively weighted parameters in six physical fractions were absolutely achieved by the C/N ratio of acid hydrolysable extracts (C/N_{AC}) (Table 1). PC2, which explained 16.7% of the total variance, include 13 positively and five negatively significant weighted parameters that reflected chiefly the C and N content of acid and hot water extracts (C_{AC} and N_{AC}, and C_{HW} and N_{HW}) associated with $F_{53\text{-}250\mu m}$ and $F_{<53\mu m}$ (Table 1). Significant PC3 loadings explained 8.8% of the total variance and reflected mostly the C and N condition of non-hydrolysable residues (Table 1).

Table 1. Principal component scores based on 41 retained variables from all minimum data set categories. Only principal components with eigenvalues > 1 and that explain > 5% of the total variance were retained.

	Principal component		
	PC1	PC2	PC3
Eigenvalue	22.81	6.85	3.62
Proportion (%)	55.65	16.71	8.82
	Rotated scores of three retained eigenvectors[B]		
$F_{250\text{-}2000\mu m}$[A]			
C/N_{AC}	-0.92		
C/N_{HW}	-0.88		
N_{AC}	0.81		
C_{NON}	0.79		
N_{HW}	0.78		
C_{AC}	0.78		
C_{HW}	0.73		
N_{NON}	0.53		0.63
RI_N	-0.43		0.68
$F_{53\text{-}250\mu m}$			
C/N_{AC}	-0.93		
C/N_{HW}	-0.92		
N_{AC}		0.94	
C_{AC}		0.92	
C_{HW}		0.86	
N_{HW}		0.79	
C_{NON}		0.67	
$F_{<53\mu m}$			
C/N_{AC}	-0.8	-0.41	
RI_C	0.49		
C_{AC}		0.93	
N_{AC}		0.92	
C_{HW}		0.81	

	Principal component		
	PC1	PC2	PC3
Eigenvalue	22.81	6.85	3.62
Proportion (%)	55.65	16.71	8.82
	Rotated scores of three retained eigenvectors[B]		
$F_{<53\mu m}$			
N_{HW}		0.78	
C/N_{NON}			-0.71
RI_N			0.61
$LF_{<1.0}$			
C/N_{AC}	-0.6		-0.62
C/N_{HW}	-0.51	-0.42	-0.64
C/N_{NON}	0.46	-0.49	
$LF_{<1.6}$			
C/N_{AC}	-0.55		
C/N_{HW}	-0.47	-0.48	-0.54
RI_C	-0.43		
C/N_{NON}		-0.49	-0.77
RI_N			
$HF_{>1.6}$			
N_{AC}	0.77	0.48	
C_{AC}	0.74	0.5	
C_{NON}	0.74		
N_{HW}	0.72	0.46	
C/N_{AC}	-0.67		
C/N_{HW}	-0.6		-0.52
N_{NON}	0.6		0.57
C_{HW}	0.54	0.57	
C/N_{NON}			-0.87

[A]$F_{250\text{-}2000\mu m}$, 250-2000 µm size macroaggregate fraction; $F_{53\text{-}250\mu m}$, 53-250 µm size microaggregate fraction; $F_{<53\mu m}$, < 53 µm size silt and clay (S+C) fraction; $LF_{<1.0}$, the light fraction with density < 1.0 g cm^{-3}; $LF_{<1.6}$, the light fraction with density < 1.6 g cm^{-3}; $HF_{>1.6}$, the heavy fraction with density > 1.6 g cm^{-3}; RI_C, recalcitrancy indices of C; RI_N, recalcitrancy indices of N; C_{HW}/N_{HW}, hot water extractable C and N; C_{AC}/N_{AC}, acid hydrolysable C and N; C_{NON}/N_{NON}, non-hydrolysable C and N; C/N_{HW}, C/N ratio of the hot water extracts; C/N_{AC}, C/N ratio of the acid hydrolysable extracts; C/N_{NON}, C/N ratio of the non-hydrolysable residues;

[B]Only meaningful loadings (with absolute values > 0.40) were included in the interpretation of the PC; Scores were sorted by absolute size within each fraction.

The relative significance of SOM quality parameters accounting for the changes induced by land use and management

Specific relevance of SOM quality parameters in conjunction with soil processes were identified through the correlation of PC scores of PCA with 22 chemical and biological parameters of whole soil (grouped into five categories, indicating the status of C pool, N pool, C transformation, N transformation, and microbial quantity and diversity, respectively) that were obtained in our previous studies (data now shown). The results showed that of the three retained PCs, only the scores of PC1 related significantly to all 22 referred parameters (Figure 1).

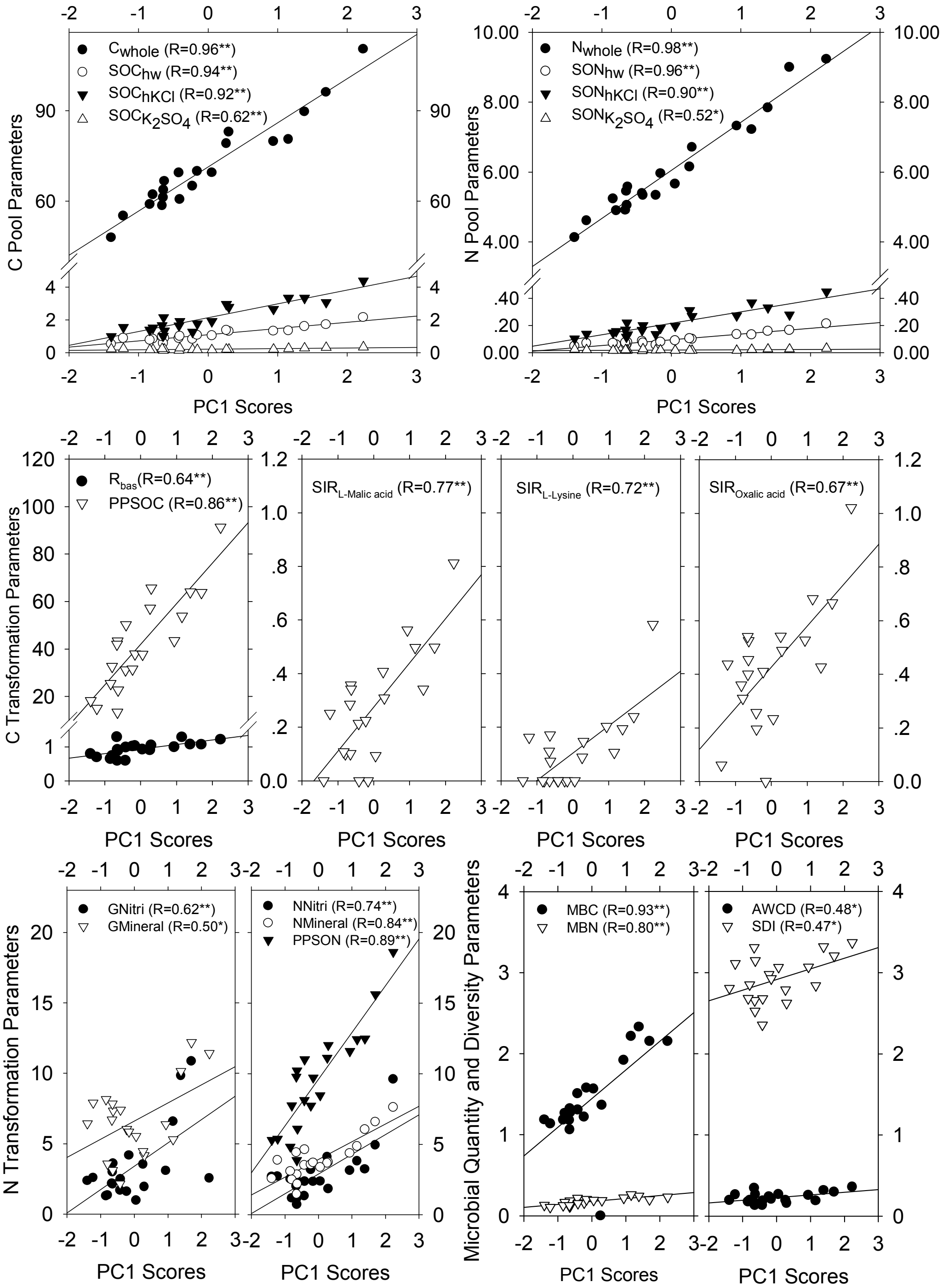

Figure 1. Correlations between the PC1 scores and the chemical and biological properties of whole soil (n = 20). C_{whole}/N_{whole}, total C and N of the whole soil, mg/g; SOC_{hw}/SON_{hw}, 70 ^{o}C hot water extractable soluble organic C and N, mg/kg; SOC_{hKCl}/SON_{hKCl}, hot 2M KCl extractable soluble organic C and N, mg/kg; SOC_{K2SO4}/SON_{K2SO4}, 0.5 M K_2SO_4 extractable soluble organic C and N, mg/kg; R_{bas}, soil basal respiration, µg CO_2-C/g/hr; PPSOC/PPSON, potential production of soluble organic C and N calculated based on a 7-day anaerobic incubation, mg N/kg; SIR, soil MicroResp^{TM} C source substrate induced respiration (for individual C substrates), µg CO_2-C/g/hr; GNitri, gross N nitrification, mg N/kg/d; GMineral, gross N mineralization, mg N/kg/d; NNitri, net N nitrification, mg N/kg/d; NMineral, net N mineralization, mg N/kg/d; MBC/MBN, soil microbial biomass C and N, mg/kg; AWCD, average well colour development of Biolog^{TM} GN plate after 96 h incubation; SDI, Shannon's diversity index. ** and * indicate the correlations are significant at the 0.01 and 0.05 probability level, respectively.

Discussion

On the PCA plots, separate clusterings were found for NF, 1R, 2R-T and 2R-W respectively. The comparison of the PC scores between NF and 1R, 1R and 2R-T, and 2R-T and 2R-W identified that only PC1, which explained three and seven times the variance explained by PC2 and PC3, was capable of accounting for all the complex differences among the tested forest sites simultaneously. And the optimum competence of candidate PC1 for best indicating the changes of SOM quality resultant from the land uses and management practices were further confirmed by its good relevance with all the whole soil chemical and biological processes (Figure 1). Therefore, all the quantitative and qualitative SOM fraction parameters with significant loadings on PC1 were the most informative measures that would be responsible for the complex impacts of land use and management on SOM quality in the tested forest ecosystem.

Digging the information suggested by Table 1 more deeply, we can find that most of the $F_{250\text{-}2000\mu m}$ associated C and N aspects were exclusively reflected by the PC1, with the absolute higher loading scores than other SOM fractions. Thus the $F_{250\text{-}2000\mu m}$ might be excavated as the most unique SOM physical indicator that PC1 represented for the illustration of land use and management induced changes. This possibly resulted mainly from the special structures of macroaggregates that have been tested dependent on live binding agents, generally do not exhibit long-term stability, and are sensitive to changes in land use and management practices (Six *et al.* 2004). In contrast, microaggregates, mineral-associated organic matter and organic matter entrapped at sites inaccessible to microbial attack or physically protected within heavy fractions belong to more stable organic matter pools with a turnover time from decades to centuries and thus resist the impact from outside (Helfrich *et al.* 2006).

Additionally, if taking a further consideration on the loading scores of PC1, we can also conclude that the C/N ratio of acid hydrolysable SOM might be another most promising SOM chemical indicator that PC1 represented for the illustration of land use and management induced changes, since the C/N_{AC} raitos of all the test physical fractions were always highly weighted variables loading on PC1 (Table 1). Possible explaination might be that acid hydrolysis by 6 M HCl is the simplest and most reproducible method to differentiate the labile from the recalcitrant SOM fractions, as evidenced in various relevant studies (Refs not shown). Therefore, the decomposition degree (as indicated by the C/N ratio) of acid extracts conducted on SOM fractions with different physical protection might be another promising chemial measure for SOM quality assessment of management impacts in the tested forest ecosystem.

Conclusion

Results from PCA based on 41 retained minimum data set and excavation of their dependence on 22 soil chemical and biological parameters that reflected whole soil processes revealed that the PC1 was most responsible for the complex changes induced by the land uses and management practices, on which the most informative and unique loadings, the macroaggregates ($F_{250\text{-}2000\mu m}$) and the C/N ratio of acid extracts of SOM physical fractions might be the most promising physical and chemical measures for SOM quality assessment of land use and management impacts in subtropical Australian forests.

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References

Six J, Bossuyt H, Degryze S, Denef K (2004) A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil and Tillage Research* **79**, 7-31.

Helfrich M, Ludwig B, Buurman P, Flessa H (2006) Effect of land use on the composition of soil organic matter in density and aggregate fractions as revealed by solid-state ^{13}C NMR spectroscopy. *Geoderma* **136**, 331-341.

Effects of nitrogen addition on fluxes and concentrations of dissolved organic matter and inorganic nitrogen under a temperate old-growth forest in northeast China

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Abstract
Soil solutions at 15 cm and 60 cm under a Korean pine and broadleaf mixed forest (>200 years old) at Changbai mountain, northeast China, were sampled using porous ceramic cups from July 2006 to October 2008, to study the effects of nitrogen (N) addition on fluxes and concentrations of dissolved organic matter and inorganic N. The soil net N mineralization and wet atmospheric depositions of N and dissolved organic carbon (C) were also measured. The addition of N sources such as $(NH_4)_2SO_4$, NH_4Cl and KNO_3 at rates of 2.25 and 4.5 g N/m^2 each year tended to increase concentrations and fluxes of inorganic N and dissolved organic N in soil solutions at 15 cm and 60 cm depths and soil net N mineralization, and it reduced leaching losses of soil dissolved organic C. The concentration ratios of dissolved organic C to dissolved organic N and special UV absorbance values in the soil solutions at both depths were smaller under the N-fertilized forest plots than under non-fertilized plots. Soil net N mineralization under the N-fertilized forest plots can contribute to the leaching losses of inorganic N from the soil. Our observations indicate that N inputs to temperate forest floors can affect the status of N and C processes in underlying forest soils.

Key words
Dissolved organic carbon and nitrogen, inorganic nitrogen leaching, forest soil, nitrogen mineralization

Introduction
Soil solution chemistry can be considered a sensitive indicator of biogeochemical processes under forest stands, responding quickly to disturbances or stresses like nitrogen input (e.g. McDowell *et al.* 2004; Pregitzer *et al.* 2004; Michel *et al.* 2006). Hence, it is important to study the dynamics of fluxes and concentrations of dissolved organic matter and inorganic nitrogen (N) in soil solutions at the various depths under different forest stands.
The addition of N sources to temperate forest floors can usually increase N leaching as DON and inorganic N from forest topsoils (e.g. McDowell *et al.* 1998; Michalzik *et al.* 2001; Pregitzer *et al.* 2004). The N inputs from forest topsoils may increase the activities of soil microorganisms and the mineralization of carbon (C) in underlying soils, thus releasing CO_2 into the soil solution (Xu *et al.* 2009). Hence, the fluxes and concentrations of dissolved organic matter (DOM) and inorganic N in soil solutions at the various depths would promote our understanding of C and N processes in the underground canopy under N-fertilized forest stands.
At present, there were many contrasting results regarding N effects on DON and DOC dynamics in forest soil solution in field and laboratory studies (McDowell *et al.* 1998, 2004; Magill and Aber, 2000; Pregitzer *et al.* 2004; Michel *et al.* 2006). Furthermore, these earlier studies mainly focused on the dynamics of DOC, DON and inorganic N concentrations in forest soil solutions sampled using zero-tension lysimeters rather than using suction cups. There are rather limited reports about the concentrations and fluxes of dissolved organic matter and inorganic N in soil solutions at the various depths under N-fertilized forest stands, especially in northeast Asia.
In this study, soil solutions at 15 cm and 60 cm under a Korean pine and broadleaf mixed forest (>200 years old) at Changbai mountain, northeast China, was sampled using porous ceramic cups from July 2006 to October 2008, to study the effects of N addition on the fluxes and concentrations of DOM and inorganic N. The soil net N mineralization and wet atmospheric depositions of N and dissolved organic C were also measured. The objectives of this work were to 1) study the effects of N addition on the fluxes and concentrations of DOM and inorganic N in forest soil solution; and 2) to assess the contribution of soil net N mineralization and wet atmospheric C and N depositions to these fluxes. The results would improve our understanding of N and C processes in underlying forest soils due to the increase in atmospheric N inputs.

Materials and methods

Forest stand site and soil properties

Field experiment was located under a Korean pine and broadleaf mixed forest (*Pinus koraiensis* mainly mixed with hardwood trees such as *Tilia amurensis, Fraxinus mandsburica* and *Quercus mongolica*, >200 years old, altitude 738 m above sea level) nearby the National Research Station of Changbai Mountain Forestry Ecology, northeast China (128°6′E, 42°24′N). The area around the mountain is a temperate, continental climate, with a long-term cold winter and warm summer. The annual mean temperature is approximately 4.1^{o}C, and precipitation averages approximately 855 mm at the bottom of the mountain, with more than 80% of rainfall from May to August. The dark brown forest soil belongs to Andosols (Food and Agriculture Organization soil classification), and the depth of litters and A-horizons is approximately 3-5 cm and 10 cm, respectively. The main properties of the soils at the various depths and groundwater table levels were reported by Xu et al. (2007, 2009).

Effects of N addition on soil solution chemistry under forest stand

Twenty-eight individual plots with 3 m x 3 m each were selected on the flatness under the mixed forest stand. Aqueous solutions of N sources such as $(NH_4)_2SO_4$, NH_4Cl and KNO_3 were respectively sprayed on the ground within four individual plots in equal monthly doses at rates of 2.25 and 4.5 g per m^2 each year, during the growing season from June to October in 2006-2008, corresponding with 5.0 mm rainfall each; tap water was added only to the control. The N addition experiments at high and low doses started from July 2006 and June 2007, respectively. According to the depth of A-horizons and the distribution of tree roots in underlying soil, two sets of porous ceramic suction cups (3.1 cm in diameter and 7 cm in height) were installed at 15 cm and 60 cm depths, respectively, to collect soil solutions of organic layers and beyond root zones (Vandenbruwane *et al.* 2008). To eliminate the disturbance of soil, soil auger with a diameter of 3.3 cm was used to establish the holes down to 15 cm and 60 cm depths, respectively, and the suction cups connected to PVC tubes were fixed closely inside the holes. The pressure inside each tube within a week at water-filled pore space more than 70% or within 24 hours after heavy rainfall was brought to approximately -70 kP_a by a portable vacuum/pressure pump (Mityvac4010, Missouri, USA). Over the years from July 2006 to October 2008, soil solutions were sampled via the stopcock attached to each tube to avoid degassing, using 100-ml plastic syringes equipped with a stopcock, and the volume of soil solution was measured simultaneously. Considering initial effects of installing the suction cups, the early two collections were discarded. These samples were rapidly transported to the laboratory and were frozen prior to the analysis of dissolved organic C, total N, NH_4^+-N and NO_3^--N concentrations.

Measurement of wet atmospheric C and N depositions and soil net N mineralization

Monthly wet atmospheric C and N depositions under such forest stand were sampled at an irregular interval dependent on intensity of precipitation using self-made rainfall collections during the whole experimental period. Dynamics of net N mineralization fluxes of the soil at 15 cm depth under all the experimental plots were measured in 2006-2008 using in-situ resin-core incubation method (Han *et al.* 2009).

Measurement of concentrations of dissolved organic C, total N, NH_4^+-N and NO_3^--N

Concentrations of DOC and total N in soil solutions were measured using a TOC/TN-analyzer (Shimadzu TOC-V_{CSH}/TN, Kyoto, Japan). Both NH_4^+-N and NO_3^--N concentrations of solutions were measured colorimetrically via the nitroprusside and hydrazine-reduction methods, respectively (Kim, 1995). Concentrations of dissolved organic N (DON) were calculated as the differences between total N and mineral N (NH_4^+-N and NO_3^--N) concentrations of solutions.

Calculation and statistical analysis

Wet atmospheric C and N depositions, and fluxes of dissolved organic matter and inorganic N in the soil solution were calculated via multiplying corresponding volume mean concentrations of solution C and N forms by amount of water flux. Means and standard errors of soil solution chemistry for each sampling date were calculated. Correlation coefficients between the tested properties of soil solutions at 15 cm and 60 cm depths were calculated using SPSS software for Windows (version 13.0). The multivariate tests and paired-sample T tests were performed using SPSS software for Windows to compare the differences in concentrations and fluxes of DOC, DON, NH_4^+ and NO_3^- in soil solutions between treatment, sampling date and soil depth.

Results and discussion

Effect of N addition on concentrations of DOC, DON and inorganic N in soil solution

NH_4^+-N concentrations in the soil solutions at 15 cm and 60 cm depths under N-fertilized and non-fertilized plots were mostly below 0.2 µg N/ml, which were much smaller than NO_3^--N concentrations in soil solutions (Figure 1). The addition of N increased the accumulation of NH_4^+-N, NO_3^--N and DON in the soil solutions at both depths (Figure 1). Thus, the export of inorganic N and DON from such forest stand was significantly increased by addition of N.

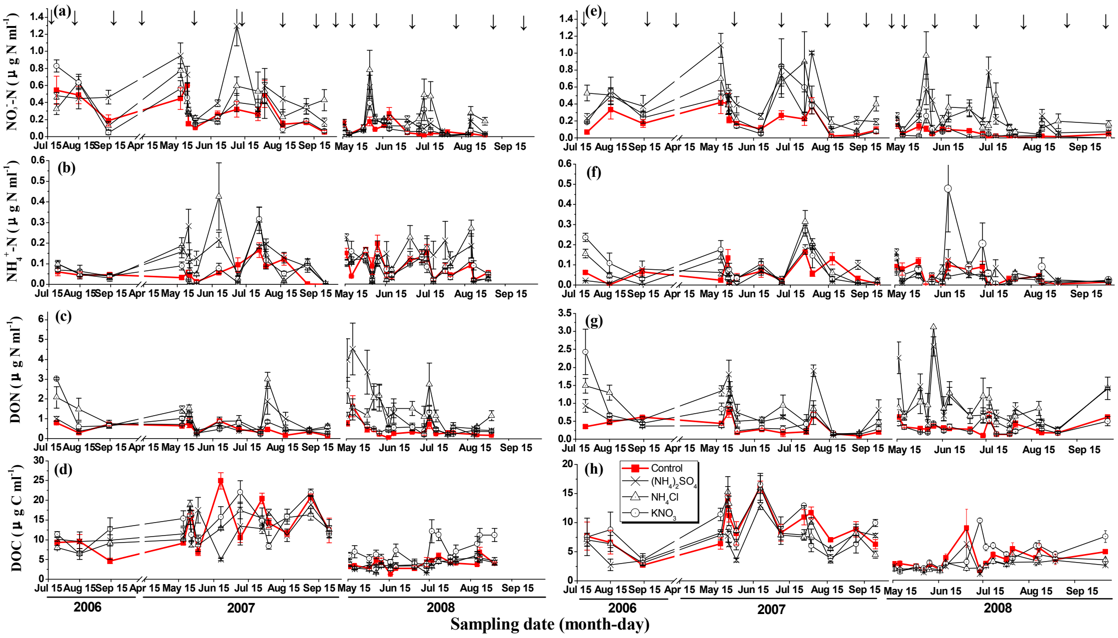

Figure 1. Dynamics of dissolved organic matter and inorganic N concentrations in forest soil solutions in 2006-2008 upon addition of N at a rate of 4.5 g /m^2 each year. a-d: soil solution at 15 cm depth; e-h: soil solution at 60 cm depth. Arrows indicate date of N addition.

The DOC concentrations in soil solutions at 15 cm depth (1.2 to 27.8 µg C/ml) throughout the period of the experiment were significantly larger than those at 60 cm depth (1.1-16.5 µg C/ml) (Figure 1d,h). The addition of N sources such as $(NH_4)_2SO_4$ and NH_4Cl tended to decrease DOC concentrations in the soil solutions at 60 cm depth (Figure 1h) and showed a small change in concentrations at 15 cm depth (Figure 1d). DOC concentrations in the soil solutions decreased with increasing soil depth under all the experimental plots to a greater degree than did DON, especially under N-fertilized plots. This phenomenon may decrease rates of DOC to DON concentrations in soil solutions at both depths upon N addition. Our observations indicated that the mechanisms for DOC dynamics under N-fertilized forest stands on a plot-scale differed from those for DON.

Effect of N addition on fluxes of DOC, DON and inorganic N in soil solution

Monthly DOC fluxes in soil solutions at 15 cm depth (0.2 to 25.0 g C/m^2) throughout the period of the experiment were significantly larger than those at 60 cm depth (0.1-16.3 g C/m^2). The addition of N sources such as $(NH_4)_2SO_4$ and NH_4Cl tended to decrease monthly DOC fluxes in soil solutions at 60 cm depth and showed a small change in fluxes at 15 cm depth. Probably, there was high amount of DOC retained in underlying mineral soils (15-60 cm) under N-fertilized forest plots. The addition of N increased fluxes of NH_4^+-N and NO_3^--N and DON in the soil solutions at both depths and tended to decrease the proportion of DON in total N fluxes.

Effect of N addition on special UV absorbance of forest soil solution

There was a relatively small special UV absorbance of forest soil solution at 60 cm depth under all experimental plots in 2007-2008 compared to the solution at 15 cm depth (Figure 2). This indicated that DOM leached from deep soil layers is characterized by high decomposability. The addition of N tended to decrease special UV absorbance of soil solutions at 15 cm and 60 cm depths, especially at the latter. Probably, N inputs to forest floors can affect the stability of DOM in soil solution.

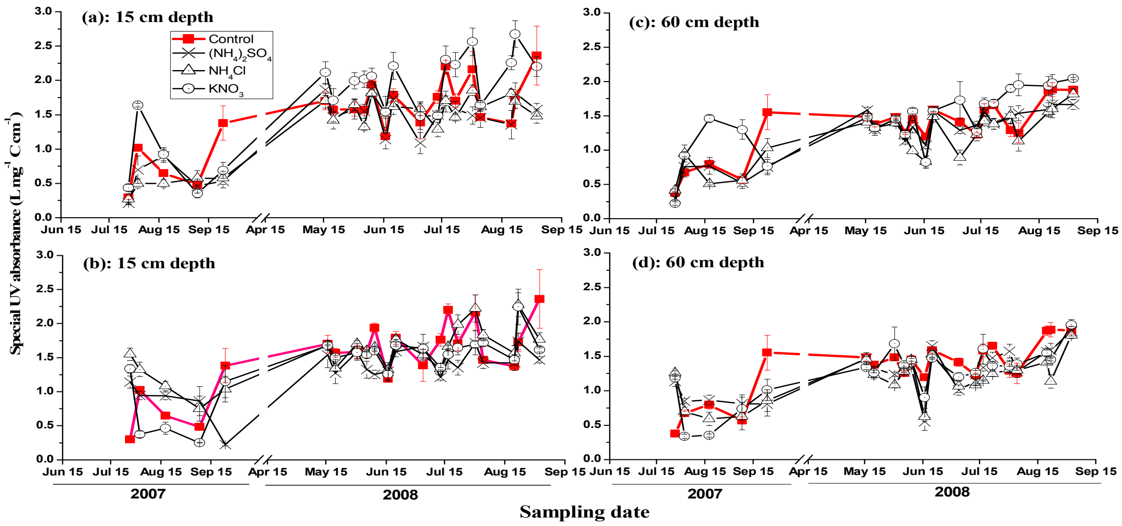

Figure 2. Dynamics of special UV absorbance of soil solutions at 15 cm and 60 cm depth in 2007-2008. a and c: N addition at a rate of 4.5 g /m^2 each year; b and d: N addition at a rate of 2.25 g /m^2 each year.

Contribution of N inputs and soil net N mineralization to N fluxes in soil solution

In combination with previous published studies, our data can be used to assess the contribution of N inputs and soil net N mineralization to N fluxes in soil solution under forest ecosystems.

Acknowledgements

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References

Han L, Xu XK, Luo XB, Cao FQ, Han SJ (2009) Effects of nitrogen addition on soil net N mineralization under a temperate old-growth forest stand. *Chin. Sci. Bull*. submitted.

Kim HT (1995) Soil Sampling, Preparation and Analysis. Marcel Dekker, New York.

Magill A, Aber JD (2000) Dissolved organic carbon and nitrogen relationships in forest litter as affected by nitrogen deposition. *Soil Biol. Biochem*. **32**, 603-613.

McDowell WH, Currie WS, Aber JD, Yano Y (1998) Effects of chronic nitrogen amendments on production of dissolved organic carbon and nitrogen in forest soils. *Water Air Soil Pollu*. **105**, 175-182.

McDowell WH, Magill AH, Aitkenhead-Peterson JA, Aber JD, Merriam JL, Kaushal SS (2004) Effects of chronic nitrogen amendment on dissolved organic matter and inorganic nitrogen in soil solution. *For. Ecol. Manage*. **196**, 29-41.

Michalzik B, Kalbitz K, Park JH, Solinger S, Matzner E (2001) Fluxes and concentrations of dissolved organic carbon and nitrogen – a synthesis for temperate forests. *Biogeochemistry* **52**, 173-205.

Michel K, Matzner E, Dignac MF, Kögel Knabner I (2006) Properties of dissovled organic matter related to soil organic matter quality and nitrogen additions in Norway spruce forest floors. *Geoderma* **130**, 250-264.

Pregitzer KS, Zak DR, Burton AJ, Ashby JA, MacDonald NW (2004) Chronic nitrate additions dramatically increase the export of carbon and nitrogen from northern hardwood ecosystems. *Biogeochemistry* **68**, 179-197.

Vandenbruwane J, Neve SD, Schrijver AD, Geudens G, Verheyen K, Hofman G (2008) Comparison of ceramic and polytetrafluoroethene/Quartz suction cups for sampling inorganic ions in soil solution. *Commun. Soil Sci. Plant Anal.* **39**, 1105-1121.

Xu XK, Han L, Luo XB, Liu ZR, Han SJ (2009) Effects of nitrogen addition on dissolved N_2O and CO_2, dissolved organic matter, and inorganic nitrogen in soil solution under a temperate old-growth forest. *Geoderma* **151**, 370-377.

Xu XK, Han L, Wang YS, Inubushi K (2007) Influence of vegetation types and soil properties on microbial biomass carbon and metabolic quotients in temperate volcanic and tropical forest soils. *Soil Sci. Plant Nutr.* **53**, 430-440.

Planning the forest roads in reforestation - cases in south Brazil

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Abstract
This work examines two cases of reforestation with *Pinus sp.* in South Brazil, with the main focus of the forest road-net. The first case indicates the importance of using a better harvest system to reduce environmental damage and increase the productive area of undulating relief. In this case it was observed the productive area is enhanced by around 28 %, where a cable system is used. The second case, soil losses in secondary forest roads have been evaluated for segments of roads with and without conservation and firebreaks on soft undulating and plain relief, with various soil texture conditions. This work clarifies the importance of conservation measures with a reduction in 11% of soil loss when using conservation measures for undulating relief and soils with sand texture predominantly and 24.3% for gently undulating to plain relief and clay texture. Development of practical code for planning of forest roads is required, considering the economical and environmental aspects during the wood harvesting.

Keyword
Environmental degradation, road-net, road density, technical parameters, planning,

Introduction
In reforestation land, it is necessary to take care with planning the forest road-net, considering the high possibility to develop different kind of environmental degradation, like erosion and the water pollution, mainly during the occasion of wood harvesting and timber hauling, where this troubles are evidenced, in function the high level of traffic (machines and trucks).
The wood harvesting and timber hauling represent a substantial part of industrial's raw material costs, and have a major influence in the sector's overall competitiveness. In Brazil this costs represent surrounded by 60 and 70%, varying in agreement to the timber transported system adopted. If this activities represent the major part of costs, they are responsible for the main environmental damage, like (soil compaction, erosion process and water sedimentation), and the quality of road-net are the fundamental importance for the damages magnitude.
Inside the reforestation cycle, the planning of forest road-net comprehends two distinctive phases where it is essential to be linked, during the implantation (Basic Road-net) and during the harvesting and timber hauling (Complementary Road-net).

Basic Road-net or Main Roads (permanent roads and all-weather roads)
For planning this Basic Road-net, it is thoughtful to provide work for stand's implantation, when the primarily focus are to attend the necessity of access and traffic the different kind of equipments and machines used for silvicultural operations: soil preparation, nursery operations, control (fire, pest and disease), cutting system, logging and transport methods, as well as the better choice for minimize the environmental impacts and reduce the costs.
The mainly characteristics observed in majority of Basic Road-net are: technical parameters are improved, like drainage system, paved (gravel or bituminous mixtures) and the road density is minimized. Through the planning of these roads, are necessary to attend the necessity of implantation the Complementary Road-net, during the wood harvesting operations (CAMARGO CORRÊA *et al,* 2006).

Complementary Road-net or Secondary Roads, Feeder Roads (seasonal roads)
During the wood harvesting operations, the Basic Road-net are amplify for attend the necessity of high level of traffic with weighty machines used for timber haulage. The FAO (2009) have some advices for planning the Complementary Road-net it was necessary to ensure that all of the elements which go into the successful combination of: road which is right for the wood harvesting operation; which is capable of safely carrying the haulage traffic; ease interference in the natural drainage patterns; minimize the damage the landscape; try to takes account of the flora and fauna and can be satisfactorily and economically maintained are included. Camargo Corrêa (2005) suggest the inclusion the environmental control during the planning the

Complementary Road-net mainly during the wood harvesting, where the erosion process are increased, exposure the water body to sedimentation.

This work aimed to explain two situations observed in Pinus sp. reforestations located in South Brazil, where the objective was to expose the possibility of grow up in the production area and environmental concept when adoption adequate planning for road-net and the importance the adoption of conservation measure in forest road during the wood harvesting.

Fist Case

The first case refer the necessity of planning the Complementary Road-net taking careful attention for choice the wood harvesting system, if the landscape are highly waved, are increase the vulnerability for development the environmental harms. In the Figures 1 and 2, are exposed different kinds of wood harvesting system.

Figure 1. Forest Road-net with conventional harvesting system (tree length)

In this case, the *Pinus sp*. was harvested thought the tree length system, where the major road density and the awful forest road-net planning it was observed. This road-net are very susceptible to surface damages (potholing, rutting, corrugation and disaggregation the soils particles) and associated with the absent of paved and waved relief, where the sandy soil are predominant, the necessity of project with erosion prevention measure are eminent, but it is not observed in field.

Figure 2. Forest Road- net integrated with cable system

This figure is around the former region, where the system adopted for harvester operations are cable, the improvement of this system in contrast with another harvesting systems consist in increase the productivity area, in this case it was appraise around 28 %, beyond the environmental advantage associated, as erosion process reduction and water preservation in susceptible areas.

Second Case

The second case refers the use of conservation measure (water bars equidistant in 50 meters) in secondary forest roads considering two sampling: undulating relief conditions with sand soil texture predominately and another in soft undulating to plain relief conditions with clay soil texture for the most part. They had been evaluated tree treatments being: road with conservation, road without conservation and firebreaks, and measure the rainfall during the period of one year, and the results are represented in Figures 3 and 4.

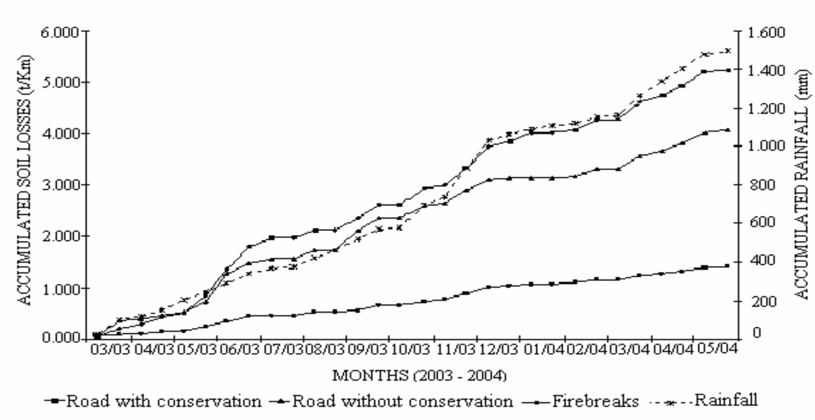

Figure 3. Secondary forest roads in soft undulating relief whit sand soil texture

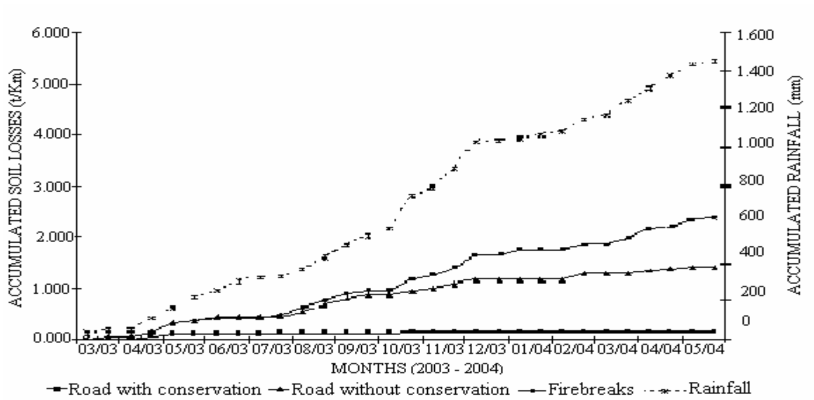

Figure 4. Secondary forest roads in plain relief whit clay soil texture

The soil losses proceeding from secondary forest road observed on the first sampling (undulating relief with sand texture predominantly) it was represented around 48,9 % in secondary roads without conservation, 38,0% in secondary roads with conservation and 13,1% in firebreaks. And in second sampling (soft to plain relief with clay texture mainly) the soil losses was represented 60.4% in secondary roads without conservation 36,1 % in secondary roads with conservation and 3,5% in firebreaks (CAMARGO CORRÊA, *et al.* 2007).

These cases wanted to collaborate for development the knowledge the susceptibility of environmental damage in forestland, and the importance of planning the wood harvesting and timber hauling and the proposition of measures were want minimize the this harms, and perhaps develop the wood harvesting practical code considering the environmental weakness associated with economical aspects.

References

Camargo Corrêa CM, Roloff G, Silva IC (2007) Real and estimative erosion through RUSLE from forest roads in two relief conditions and four soils profile (Piracicaba/SP). *Sci. For.***76**, 57-66. *http://www.ipef.br/publicacoes/scientia/nr76/cap05.pdf*

Camargo Corrêa CM, Malinovski JR, Roloff G (2006) Bases for planning the Road - net in South Brazil reforestation. (Curitiba/PR.). *Floresta* **36**(2) 277-286. http://ojs.c3sl.ufpr.br/ojs2/index.php/floresta/article/viewFile/6450/4641

Camargo Corrêa CM (2005) Soil loses and water quality proceeded from Forest roads in Catarinense Plato. These Silvicultural Area – Forest Engineering / Federal University of Paraná. Curitba/Pr. 158 p. http://www.floresta.ufpr.br/pos-graduacao/defesas/pdf_dr/2005/t192_0237-D.pdf

FAO–Food and Agriculture Organization (1998) visited 29/10/2009, in http://www.fao.org/docrep/W8297E/w8297e00.HTM

Quantified soil dynamics and spatial fragmentation within the shifting agricultural landscape in southern Cameroon

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Abstract
This research used scientific modeling tools to produce quantitative information on the effects of shifting agriculture on soil and spatial pattern of landscape dynamics in the area. An analysis of farming system led to the development of a conceptual model of the spatio-temporal dynamics of shifting agriculture, including transition matrices of rotational cycles. The study of soil variability showed that 30-35% of the total variance of some topsoil (0-20 cm) properties was due to the influence land use practices. A robust quantitative multi-criteria method was then developed that selected five soil properties (pH, calcium, available phosphorus, bulk density and organic carbon) that are the most sensitive to these agricultural practices. Empirical models of linear/quadratic fractional rational functions were successfully fitted to time series soil variables to derive quantitative measures on temporal changes in soil with land use. Multi-spectral satellite imagery was able to map with 80% accuracy the extension front of shifting agricultural landscape and the most dynamic land cover types (crop fields, young fallows), which shift every season and every year. Data and methods produced are useful for soil quality assessment and spatio-temporal dynamic simulation in order to guide decision-making for sustainable land-use planning and forest resources management.

Key words
Shifting agriculture; Farming systems analysis; Soil dynamics; Landscape fragmentation; Rain forest; Southern Cameroon.

Introduction
In the tropical rain forest zone of Southern Cameroon, the spatial pattern of the shifting agricultural land use system is a landscape mosaic system (Forman 1995), which is defined here as a spatial and temporal heterogeneity of aggregated elements of distinct boundaries, where various fallow types, various food crop fields, various perennial plantation types, undisturbed forest, and settlement areas are repeated in similar form over the landscape. This leads to a dynamic process acting in soil and on the spatial pattern of land use/Land cover (LULC) within the mosaic system. Beside the small-scale farmers' agriculture, the sustainable use and management of the national forests has become a challenge at national as well as international levels (ITTO 1990). In such a context of multifunctional use of the space, better land management practices that can ensure efficient use of energy and nutrient capital from soil-vegetation complex, and minimize land use conflicts should be promoted. However, this can only be effective if based on thorough knowledge on integrative indicators of the current status of the agricultural production capacity of land and their changes over time. This is what motivated the research reported in this paper which main objective was to provide quantitative information, developed through modelling processes, on short and long-term effects of shifting agriculture on soil and the landscape dynamic in space.

The research design and methods
The study area is located between 2º47' - 3º14' N and 10º24' - 10º51' E. It belongs to the mid-altitude dense moist evergreen Biafran forest of Cameroon (Gartlan 1989). Two rainy seasons account for 1600-2000 mm of annual rainfall. Most soils are Ferralsols and Acrisols (FAO-ISRIC 2006). The area is sparsely populated. Selective industrial logging and extensive shifting agriculture are the most important land use activities.
In four representative villages of the area, a synchronic approach for data collection was combined with diachronic monitoring of plots during the two-year cropping period and after five subsequent years. LULC treatments (10 in total) were chosen based on actual agricultural production cycles (Figure 1) described in Yemefack (2005, Chapter 2). Samples were taken with 3-4 replications in each village. In selected LULC patches, composite soil samples were collected, at three depths (0-10, 10-20, and 30-50 cm). Soil samples were analysed in the IRAD laboratory for pH, organic matter, available phosphorus, exchangeable bases, exchange acidity and particle size distribution, using procedures described in Van Reeuwijk (1993). Surface areas of 293 crop fields opened within three years by 35 households were measured. 33 plots were monitored from the first year of cropping to seven years.

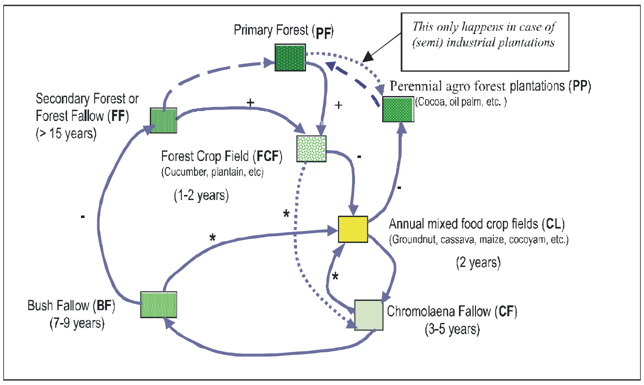


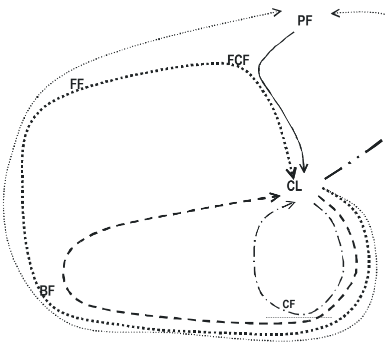
Figure 1. Observed transitions between land uses. Adapted from Yemefack (2005, Chapter 2)
Key:( ) Common transitions; ( ) Infrequent transitions; ( ) PF recovery after definite abandonment; (+) patches can split (fragmentation); (-) patches can merge with others of the same type (consolidation); (*) patches can merge with those of other types.

Investigating landscape spatial fragmentation, two questions guided our research: (i) Can Landsat-7 ETM+ imagery be used to map various LULC of the area? (ii) At which level of aggregation could this landscape structure be characterized in terms of composition and spatial configuration? In two sample sub-areas (Ebimimbang area on Acrisols and Mvie area on Ferralsols), the geographic coordinates of the centre of 158 LULC patches were recorded with a GPS six weeks before the image was taken on the 31 March 2003. Descriptive statistics, analysis of variance and means separations (Tukey's method), principal component analysis, cluster analysis, discriminant analysis, and geostatistical analysis were applied to different datasets designed purposely for each specific objective. Detailed descriptions of these analyses are giving in Yemefack (2005). The analyses were carried out with R environment (Ihaka and Gentleman 1996). Spatial analysis and remote sensing processing were done using ILWIS (ITC ILWIS Unit 2001).

Results and discussion

Dynamics of shifting agriculture

The analysis of farmers' field size distribution and the conceptual model of land use dynamic exposed the issue of rotational fallow systems, which tend to replace the ideal shifting cultivation in which short-term cropping alternates with secondary forest on a plot. This has shown (Figure 2) that 1/5 of food crop field plots were based on short rotational fallow cycles (RSFS), about 1/2 on long rotational fallow cycles (RLFS), 1/5 on very long fallow cycles (RVFS), and 1/10 on forest conversion (FCS). If the shorter fallow cycles are sustainable, this may require intensification: tighter integration into the market economy and some purchased inputs, with special attention to nutrient cycling and soil management.



Key:	Cycle	Area (%)	Household (%)	
	CL-BF-CL (RSFS)	19	32	Food crop production cycles
	CL-CF-BF-CL (RLFS)	52	52	
	CL-CF-BF-FF-FCF-CL (RVFS)	17	11	
	PF-FCF (FCS)	12	5	
	PP cycle	3-25 (including elites' plantations)		
	PF recovery	unknown		

Figure 2. Cycle proportions of shifting agricultural land use management in southern Cameroon. Adapted and modified from Yemefack (2005, Chapter 2).

In this study, 35 households cleared 95 ha in three years, of which 88% of the area cleared for crop fields came from fallow lands and only 12% from primary forest (Figure 2). However, with the involvement of

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elites in agricultural plantations, net deforestation is probably occurring, since their plantation plot sizes are far larger than those of small farmers. This brings the total proportion of PF in the cleared area to about 40% when including elite plantations.

Soil variability in the study area

For a better understanding of complex relations between soil properties, environmental factors and land use systems, sources of soil variability were evaluated at four scales: region, village, plot and laboratory (Yemefack *et al.* 2005). This four-scale study was able to explain for several variables, an encouraging 80% (for less sensitive soil variables) to 95% (most sensitive ones) of the overall soil variation; with 5 to 70% by regional factors, 3 to 35% by local factors, 1 to 10% by within-plot factors, and less than 5% by laboratory errors. Land use practices significantly ($p<0.05$) influenced topsoil variation at village level and accounted for 30-35% of topsoil (0-20 cm depth) variation. Thus, because regional factors of soil variability are more stable over time, our research should focus chiefly on processes and factors occurring at local-scale level under the influence of a dynamical land use system.

Soil dynamics under shifting agriculture

Soil behaviour in time was here quantified by the most sensitive soil properties to shifting agricultural practices and their mathematical model as a function of time.

Most sensitive soil properties: A multi-criteria quantitative selection procedure was developed (Yemefack *et al.* 2006b) and applied to a set of 13 soil variables collected within a chronosequence of shifting cultivation system. Five soil properties (pH, exchangeable Ca, available P, bulk density and organic carbon) were selected as the most affected by the practices. These can be used individually or in combination to assess the effect of this practice on soil condition. The five indicators could be easily interpreted in terms of their relation to land management practices and land use changes (Yemefack *et al.* 2006b).

Change in soil properties with time: The five most sensitive soil properties were used individually to model the behaviour of soil over time, the time being represented by a land use chronosequence (Yemefack *et al.* 2006c). Within the longest cycles of shifting cultivation (SC) and agroforest cocoa plantations (PP), each soil property changes as a function of time *t,* with $P(t) = P_0 + f(t)$

where $P(t)$ is the value of the soil property P at time t, P_0 is the value of soil property P at time $t=0$ (under the forest cover, PF), and $f(t)$ is the change function of time. Since our interest for this study was to model the change, not the absolute values, we converted each variable to a proportional deviation (*Pd*) from the reference sites PF. Pd values were plotted against time to determine the form of $f(t)$ and attempts were made to fit suitable functional forms, of which low-order fractional rational functions proved to be most appropriate. In this case, proper linear/quadratic fractional rational functions,

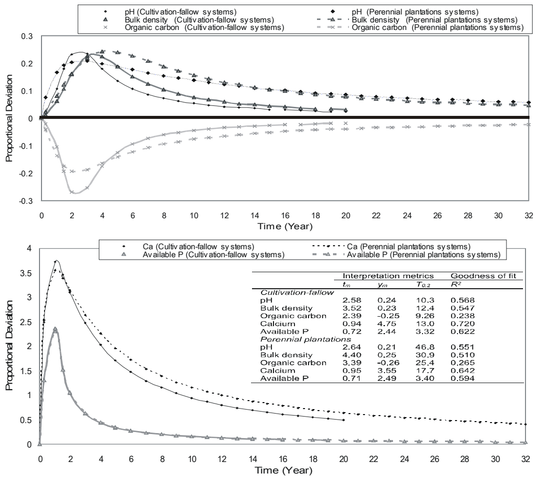
$$f(t) = \frac{a + bt}{1 + ct + dt^2}$$

showed a reasonable shape to model changing soil properties in response to events such as land clearing, burning, cropping, fallowing and PP. The fitted functions (Figure 3) were used to evaluate metrics describing soil behaviour over time: maximum proportional deviation from the base state (y_m), time to reach this maximum (t_m), and relaxation time towards the original value (t_p = time after t_m at which the curve reaches some predefined proportion of recovery).

The fitted function explained 50 to 80% of soil dynamics for the first four variables in the 0-20 cm layer on both Ferralsols and Acrisols but only 25% for organic carbon. These functions showed a very quick reaction to forest conversion for calcium, available P and organic carbon which maxima are reached at the end of the first year. Soil reaction and bulk density showed significant changes a bit later (2.5 to 3.5 years). The low contribution (only 25%) of organic carbon to the models could be explained by the strong fluctuations of data during the years.

Landscape spatial structure

Investigating statistical relationships between LULC types, Landsat-7 ETM^+ satellite imagery and landscape spatial fragmentation due to the conversion of tropical rain forest to shifting agriculture (Yemefack *et al.* 2006a), common statistical techniques applied to spectral point data and derived indices led to a suitable strategy for consolidating some of the current LULC types in the process of LULC aggregation for improving image classification. Thereafter, the application of the Maximum Likelihood Classifier (MLC) for supervised classification provided a LULC map (Figure 4) with the highest accuracy (81%) after consolidation of perennial LULC types into one mapping unit (bush fallow, forest fallow and cocoa plantations).



	Interpretation metrics			Goodness of fit
	t_m	y_m	$T_{0.2}$	R^2
Cultivation-fallow				
pH	2.58	0.24	10.3	0.568
Bulk density	3.52	0.23	12.4	0.547
Organic carbon	2.39	-0.25	9.26	0.238
Calcium	0.94	4.75	13.0	0.720
Available P	0.72	2.44	3.32	0.622
Perennial plantations				
pH	2.64	0.21	46.8	0.551
Bulk density	4.40	0.25	30.9	0.510
Organic carbon	3.39	-0.26	25.4	0.265
Calcium	0.95	3.55	17.7	0.642
Available P	0.71	2.49	3.40	0.594

Figure 3. Linear/quadratic fractional rational functions fitted to soil properties (0-10 cm) dynamics under two land use chronosequences (food cropping-fallow system and perennial plantation) as shown by proportional deviations from the reference under primary forest over time.

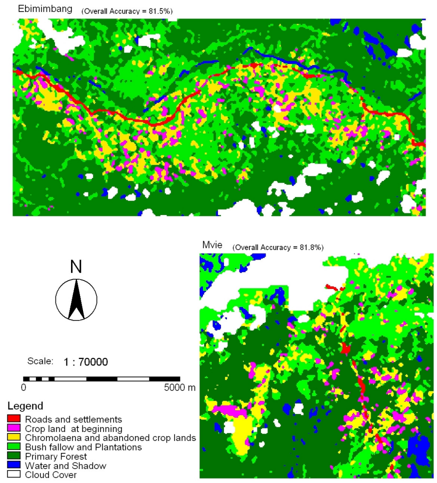


Figure 4. Spatial configuration of the two sub-areas based on the Maximum Likelihood supervised classification.

Concluding remarks

- The short rotational fallow cycle is increasingly being used due to the farmers' desire to replace cash income from cocoa with cash food crops. This may require intensification with special attention to nutrient cycling and soil management. This land use practice significantly influence topsoil variation and accounted for 30-35% of the total variance.
- Five soil properties (pH, exchangeable Ca, available P, bulk density and organic carbon) are the most affected by the shifting agricultural practices in topsoil. Interpretation metrics derived from their functions (linear/quadratic fractional rational functions) in time are useful figures for supporting decision in defining and timing any intervention action.
- From multispectral remote sensing, only crop fields and short fallow patches were most accurately classified by the maximum likelihood classifier with over 80% accuracy.
- Data and methods produced are useful for soil quality assessment and spatio-temporal dynamic simulation in order to guide decision-making for sustainable land-use planning and forest resources management.

References

FAO-ISRIC (2006) 'World Reference Base for soil resources.' (FAO: Rome)

Forman RTT (1995) 'Land mosaics: The ecology of landscapes and regions.' (Cambridge University Press: Cambridge, UK)

Gartlan S (Ed.) (1989) 'La conservation des écosystèmes forestiers du Cameroun.' (UICN: Gland, Suisse et Cambridge, UK)

Ihaka R, Gentleman R (1996) R: A Language for Data Analysis and Graphics. *Journal of Computational & Graphical Statistics* **5**, 299-314.

ITC ILWIS Unit (2001) ILWIS 3.0 Academic user's guide. In. pp. 520. (ITC: Enschede, NL)

ITTO (1990) 'ITTO Guidelines for Sustainable Management of Natural Tropical Forests.' (Yokohama, Japan)

Van Reeuwijk LP (1993) 'Procedures for soil analysis.' (ISRIC: Wageningen, The Netherlands)

Yemefack M (2005) 'Modelling and monitoring soil and land use dynamics within shifting agricultural landscape mosaic systems.' (ITC Enschede and Utrecht University: Enschede, The Netherlands)

Yemefack M, Bijker W, De Jong SM (2006a) Investigating relationships between Landsat-7 ETM^+ data and spatial segregation of LULC types under shifting agriculture in southern Cameroon. *International Journal of Applied Earth Observation & Geoinformation* **8**, 96-112.

Yemefack M, Jetten VG, Rossiter DG (2006b) Developing a minimum data set for characterizing soil dynamics under shifting cultivation systems. *Soil & Tillage Research* **86**, 84-98.

Yemefack M, Rossiter DG, Jetten VG (2006c) Empirical modelling of soil dynamics along a chronosequence of shifting cultivation in southern Cameroon. *Geoderma* **133**, 380-397.

Yemefack M, Rossiter DG, Njomgang R (2005) Multi-scale characterization of soil variability within an agricultural landscape mosaic system in southern Cameroon. *Geoderma* **125**, 117-143.

Soil fertility of *Pinus taeda* L. areas with low growth rates in Jaguariaíva – Paraná State, Brazil

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Abstract
Pine forests in Brazil have reached a high level of productivity. However, there are many areas with low rate of plant growth, associated with low soil fertility. Seven sites showing low rate of plant growth were selected and sampled for soil and litter analysis, in order to establish the limiting factor of soil fertility. Soils samples were collected within the following depths (0-20, 20-40 and 40-60 cm) and analyzed for soil fertility properties. Total soil concentration of K was also determined. Litter accumulation and its nutrient concentrations were established for each site. The results indicated that the soils were very acid with Al saturation higher than 75%, for all samples. Ca, Mg and K availability varied from < 0.1 to 0.4 < 0.1 to 0.2 $cmol_c /dm^3$, and 2.5 to 21.5 mg/dm^3, respectively. The total concentration of K varied from 97 to 360 mg/kg of K, indicating a very low level of K reserves. The litter accumulated on the soil surface showed the influence of plant age and insufficient decomposition, forming a typical moder profile. The data suggested that lime and nutrient applications may be necessary to promote plant growth.

Key words
Pinus taeda, forest soil, soil acidity, soil nutrients reservoir, Cerrado, Brazil.

Introduction
During the 60´s the Brazilian government promoted a large reforestation program in the south. Pine species were selected reflecting the favorable subtropical climate condition and the original low soil fertility. Today, the pine reforestation is concentrated in the three southern states, where in Paraná the covering area reaches 686,453 ha (ABRAF 2007).
The good plant adaptability has been shown by the high productivity (Higa and Silva 2008). Depending on site quality, this productivity varies from 15 to 56 $/m^3/ha/y$ (Mainarde *et al*. 1996). Despite the low fertility requirement, there are indications that nutritional lack has been limitimg pinus growth under some conditions (Chaves and Corrêa 2003; 2005). This fact has been observed in reforestations occupying earlier Cerrado vegetation areas, which are well known to have very low soil fertility.
Fertilizer application is not usual practice in pine plantations so nutrient depletion exacerbated by log extraction without nutrients return can start to impact on plant growth on poor soils after the second cut cycle.
Soil chemical and plant tissue analysis are the most used tools to evaluate the abundance of nutrients or toxic elements which can compromise plant growth (Reissmann 1981). These tools have been shown to be effective to distinguish different growth sites in the Brazilian pinus plantation (Wisniewski and Reissmann 1996; Vogel 2003). However, there were conditions where these tools had low efficiency like in Cerrado soil (Chaves and Corrêa 2003; 2005) where soils are very likely to have more than one limiting factor.
Litter accumulation on forest floor and its quality can also be used to evaluate pine growth sites (Mead 1984). For the same age plantation, an inverse relationship was observed between litter accumulation and plant growth (Wisniewski and Reissmann 1996).
Located in the north of Paraná State, Jaguariaiva region is the transition area between subtropical and tropical climate condition. The regional natural vegetation reflects this climate transition where subtropical forest of araucária, subtropical grassland and Cerrado (Brazilian savanna) share the soil occupation. Also, two kinds of sandstone are the major parent materials forming soils, giving a sandy texture to the soils as well as low nutrient reserves. The region has lower pinus growth rates compared to others region and responded to nutrient applications as organic residue (Rodrigues 2005). Our objective was to collect and analyze soil and litter in order to identify factor limiting plant growth.

Material e methods
Commercial pinus plots plantations were selected, near Jaguariaíva city. The region is located on the second

paranaense high plain, with altitudes between 960 to 1320 m. Furnas and Itararé sandstone are the soil parent material for the region. The regional climate is a transition between subtropical and tropical, with mean annual precipitation ranging from 1440 to 1600 mm and mean temperature from 17 to 19ºC. Frost occurs almost every year.
Using a 50000 ha inventory, it was selected seven sites. Five of them had age 4 and 5, one 11 and one 17 years old. The plantation was made 2 x 3m spacing and all was at least one time cropped with pinus or eucalyptus. For each plot it was selected an area of 1.2 ha (96 x 112 m), representing 34 lines. Then, it area was split in four line of 8 lines where it was collected eight soil samples within 0-20, 20-40 and 40-60 cm depth, in order to form one compost sample for each depth.

In the same places where were collected the soil samples were collected the litter (L, F and H) horizon. After dry at 60 ºC, the litter samples were weighted, ground using Wiley type. Then samples were submitted a dry combustion (500 ºC) and attack with HCl 3 mol/L, and analyzed for macro and micronutrients according with Martins and Reissmann (2007).

Soil samples were dried, sieved and analyzed for pH ($CaCl_2$ 0,01M – 1/2.5 soil/solution), Al toxic (extractable Al – KCl 1 M), $H^+ + Al^{+3}$ (buffer capacity until pH 7,0), available Ca and Mg (extractable KCl 1 M), available K and P (Mehlich I extraction) and total organic Carbon (C) (Walkley-Black methods), following Marques and Motta (2003). Total, non exchangeable, and exchangeable K were determined by using concentrated HF, boiling HNO_3 1N, and ammonium acetate 1 mol/L, respectively. (MELO, 1994)

Results and discussion

Soil Fertility

Soil results (Table 1) indicated that the soil were very acid high with low pH, high exchangeable Al and saturation. It was expected since the soil was natural acid and not lime was applied on pinus plantation. High values of (H + Al) can be associated with low pH and high organic C, and indicated high buffer capacity. Following the high soil acidity, very low level of Ca and Mg was observed, suggesting possibility of deficiency. Application of lime as Ca and Mg source is recommended, especially because there are large lime reservoirs close and price was accessible.

Table 1. Mean values of pH, Al, (H + Al), m % (Al saturation), C (total organic carbon), Ca, Mg, and P (Mehlich I), for seven soils under pinus in the Jaguariaiva region – Brazil.

	pH			Al^{+3}			$(H^+ + Al^{+3})$			m (%)		
	1*	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
						$cmol_c/dm^3$					%	
P1	3,8	4,1	4,1	2,7	1,7	1,6	10,9	7,9	7,1	81	81	81
P2	4,0	4,2	4,2	1,5	1,2	1,1	6,5	5,2	4,7	81	76	77
P3	4,1	4,1	4,2	1,6	1,3	1,0	9,4	8,4	7,8	78	75	76
P4	3,9	4,1	4,1	1,9	1,4	1,2	8,0	5,8	5,5	85	80	82
P5	3,9	4,0	4,1	1,3	0,9	0,8	6,5	5,5	5,3	84	77	75
P6	4,0	4,1	4,1	1,5	1,1	0,9	7,2	6,0	5,9	85	84	81
P7	4,0	4,1	4,1	1,6	1,3	1,2	8,5	8,1	7,8	84	84	85
	C			**Ca**			**Mg**			**P**		
	g/dm^3					$cmol_c/dm^3$					mg/dm^3	
P1	29,9	24,5	18,0	0,4	0,3	0,3	0,2	0,1	0,1	6,4	3,2	1,9
P2	25,0	17,8	17,2	0,3	0,3	0,2	0,1	0,1	0,1	2,9	1,0	0,4
P3	33,6	24,0	19,7	0,3	0,2	0,2	0,2	0,1	0,1	2,6	0,4	0,4
P4	18,2	16,3	12,0	0,2	0,2	0,2	0,1	0,1	0,1	2,3	1,0	0,4
P5	17,7	13,8	13,9	0,2	0,1	0,2	0,1	0,0	0,1	0,4	0,2	0,1
P6	20,3	15,3	13,0	0,2	0,1	0,1	0,1	0,0	0,1	0,7	0,6	0,2
P7	24,9	16,3	13,4	0,2	0,1	0,1	0,1	0,0	0,0	0,5	0,1	0,2

*1 – 0-20 cm depth; 2 – 20-40 cm depth; 4-60 cm depth.

The same was observed for available K (Mehlich I) as well as total and non exchangeable (HNO_3) (Table 2). The level of K total obtained was bellow to others in the south (Martins *et al.*. 2004, Nachtigalll and Vahl 1989 and Melo 1994) but similar to observed to Cerrado region (Ritchey 1982). Since the non exchangeable K has been considered a medium and long term reservoir farmer cannot afford to have this reservoir to supply K for these soil types. This suggests that K can be a limiting factor to pinus growth, fertilizer application need to be test. Phosphorus can also be problem since low and very low levels were obtained (Payn *et al.*. 1988).

Table 2. Mean values (mg/kg) of total, non-exchangeable (HNO_3), Mehlich I, and exchangeable K (ammonium acetate) for seven soil under pinus in the Jaguariaiva region – Brazil.

	Total			HNO_3			Mehlich I			Ammonium acetate		
	1*	2	3	1	2	3	1	2	3	1	2	3
P1	117	138	147	33,0	24,3	25,5	20,5	12,7	10,7	14,8	9,3	5,5
P2	250	357	357	30,5	23,0	24,0	14,6	7,8	7,8	12,0	4,5	3,3
P3	197	196	192	39,5	28,0	21,5	21,5	13,7	12,7	21,5	10,8	5,5
P4	319	315	360	31,5	25,3	26,5	12,7	8,8	5,9	9,3	4,8	2,5
P5	98	103	107	13,8	10,5	9,8	12,7	7,8	7,8	8,0	3,3	4,3
P6	168	213	192	18,0	14,8	11,5	10,7	5,9	5,9	8,3	4,3	4,3
P7	109	164	97	25,0	19,0	15,5	16,6	11,7	7,8	17,0	10,3	6,8

*1 – 0-20 cm depth; 2 – 20-40 cm depth; 4-60 cm depth.

Litter and nutrients

The amount of litter on Forest floor was affected by forest age with the plantations with 11 and 17 high values (Table 3). However, the age could not explain the high values observed site number 7. This fact could be related with soil fertility, but it was not possible to confirm give the influence of first plantation.

The carbon concentration did not vary among sites so the amount of C retained on litter was direct related with total litter mass (Table 3). Very low concentration of P, K, Zn and Cu observed (Table 3) in our study indicated that the amount of nutrients on litter is small. Also, this fact can be result of low nutrients availability or leaching process (mobile elements). In opposite way, high level of Fe and Mn obtained can be result of very low soil pH. Theses fact can be also give by Zn deficiency which is very common under Cerrado condition.

Table 3. Mean values for macro and micronutrients in litter for seven sites under pinus in the Jaguariaiva region – Brazil.

Sites	Age	Litter	C	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	years	kg/ha	g/kg						mg/kg			
1	5	3404	472	6,7	0,77	0,50	3,44	0,80	297	605	6,9	4,48
2	5	4347	465	7,1	0,73	0,55	2,64	0,91	437	177	3,6	3,26
3	5	3541	473	7,6	0,67	0,70	3,49	0,70	419	416	10,9	4,16
4	11	24656	470	10,5	0,73	0,45	0,80	0,11	526	107	4,5	4,17
5	5	4093	479	8,0	0,58	0,56	0,80	0,76	422	1107	6,6	1,33
6	17	13069	472	12,2	0,95	0,51	0,79	0,23	979	76	1,4	1,55
7	5	16240	459	12,4	0,96	0,49	0,59	0,25	1075	78	1,2	1,73

Conclusions

Soil from Jaguariaiva region showed to be very acid, with low nutrients availability and K reserve. The litter showed to be very poor and also may not contribute to supply plant growth. Lime and fertilizer application may be necessary to reach similar yield from others states regions.

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References

ABRAF (2007) Anuário estatístico: ano base 2006. ABRAF. Brasília, 80 p.

Chaves R, de Q Corrêa GF (2005) Macronutrientes no sistema solo-*Pinus caribea Morelet* em plantios apresentando amarelecimentos das acículas e morte de plantas. *Revista Árvore* **29**(5), 691-700.

Chaves R, de Q. e Corrêa GF (2003) Micronutrientes no sistema solo-*Pinus caribea Morelet* em plantios apresentando amarelecimentos das acículas e morte de plantas. *Revista Árvore* **27**(6), 769-778.

Higa AR, Silva LD (2008) Situação atual e perspectivas do melhoramento genético de pínus e eucaliptos no Brasil. In: I Encontro Brasileiro de Silvicultura. 10 a 12 de novembro de 2008. Curitiba, Paraná – Br. – Piracicaba: IPEF/FUPEF/ PTSM. pp.105-115

Mainarde GL, Schneider PR, Finger CA (1996) Produção de Pinus taeda L. na Região de Cambará do Sul, RS. *Ciência Florestal* **6**(1), 39-52.

Marques R, Motta ACV (2003) Análise química do solo par fins de fertilidade. In: Lima. M. R. (org.). Manual de Diagnóstico da Fertilidade e Manejo dos Solos Agrícolas. 2º ed. Curitiba: Departamento de Solos e Engenharia Agrícola. cap. 5, p. 82-101.

Martins APL, Reissmann CB (2007) Material vegetal e as rotinas laboratoriais nos procedimentos químico-analíticos. *Scientia Agraria* **8**(1), 1-17.
Martins R, Melo V de F; Serrat BM (2004) Reserva de mineral de potássio em solo dos Campos Gerais, estado do Paraná. *Revista Ceres* **51**(296), 521-533.
Mead DJ (1984) Diagnosis of nutrient deficiencies in plantations. In "Nutrition of Plantation Forests". (eds GD Bowen, EKS Nambiar) pp. 259-291. (Academic Press, London).
Melo V deF (1994) Relação entre a reserva de solos e a produção e nutrientes em povoamentos de *Eucalyptus saligna* Smith, no Rio Grande do Sul. Viçosa. 145p. (Dissertação de mestrado).
Nachtigall GRE, Vahl LC (1989) Formas de potássio em solos da região sul do estado do Rio Grande do Sul. *Rev. Bras. Ci. Solo* **13**(1), 7-12.
Reissmann CB (1981) Naehrelementversorgung und Wuchsleistung von Kiefernbestaenden in Suedbrasilien. Freiburg i. Br. Alemenha: Albert Ludwig Universitaet. Tese de Doutoramento. 159 p.
Ritchey KD (1982) O potássio nos oxissolos e ultissolos dos trópicos. Piracicaba, Inst. da Potassa e Fosfato. (Boletim Técnico, 7).
Rodriges CM (2005) Efeito da aplicação de resíduos da indústria de papel e celulose nos atributos químicos, físicos e biológicos do solo, na nutrição e biomassa do *Pinus taeda L.* Curitiba: UFPR. 109p. (Dissertação de mestrado).
Vogel HLM (2003) Crescimento de Pinus taeda L. relacionado a doses de N, P e K e sua diagnose nutricional pelo DRIS. Rev. *Ciência Florestal* **13**(1), 182-188.
Wisniewski C, Reissmann CB (1996) Deposição de serapilheira e nutrients em plantios de Pinus taeda L. na região de Ponta Grossa – PR. *Arq. Biol. Tecnol*. **39**(2), 435-442.