PREFACE

This is my 60 credits Master thesis in Ecology study program at the Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences (UMB).

First, I would like to thank my supervisor Professor Mikael Ohlson, Norwegian University of Life Sciences, for his valuable advices, comments, grate support and progressive ideas for the improvement of the thesis. He is really a great and generous person in my eyes.

I would also like to thank Post Doc. student Marit Helene Lie for her help and for her optimism and enthusiasm.

Further, I would like to thank Annie Aasen, engineer at Ecology and Natural Resource Management department for her help in laboratory work and also like to thank Signe Kroken, engineer at Mathematical Sciences and Technology department for her help and good company.

Thanks a lot.

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Ås, 07 February, 2012

SUMMARY

Background and aim: Forest soils store a substantial amount of carbon and carbon is a key component is soil organic matter. During the stand development of a forest site, a proportion of the carbon sequestrated by trees and other vegetation is transferred into the soil by litterfall and roots, and thereby building up a soil carbon stock. The main goal of my study was to estimate the soil carbon pools in 55 and 15 years old Norway spruce (*Picea abies*) forest stands that are established on formerly open grazing land. To show how the soil carbon pool change when an open land is forested. I have also estimated the soil carbon pools in two open grazing lands adjacent to the forest stands. My main hypothesis was that the soil carbon pool will increase over time following forestation.

Location: The study sites were located in Ås community in the north-eastern part of Akershus County, south-eastern part of Norway.

Methods: A total of 200 soil samples including vascular plants and bryophytes were collected in a restricted random procedure considering the variation along ecological gradients in aspects, nutrient conditions, light supply, topographic conditions and soil moisture etc. The soil samples, reaching down to a depth of 15 cm, were collected with a steel cylinder corer that had a diameter of 5.8 cm. All samples were soil cores included the entire organic top soil layer (a few cores were less than 15 cm long because of shallow soil and presence of rocks and boulders). The amount of carbon in the soil was then estimated by dry combustion.

Results: The overall mean carbon content across all study sites was 2092 ± 993 g/m^2 (± SD) with site-specific means ranging from 1043 ± 233 g/m^2 to 3297 ± 828 g/m^2. The soil carbon pool was largest in the 55 years old forest stand, whereas the 15 years old forest stand had the lowest amount of carbon across the study sites. The results showed different trends and variation in the amount of carbon content between and within the study sites. In particular there was a large variation in the size of the soil carbon pool across fine spatial scales.

Conclusion: My results showed that the soil carbon pool was largest in the oldest forest stand and that it is likely that the soil carbon pool will increase over time when open grazing land is forested. My study also showed that the size of the organic top soil carbon pools is highly variable across fine spatial scales.

For more accurate monitoring of soil carbon pool sizes and dynamics, it is important to collect more field data across a broad range of spatial scales in different types of ecosystems.

CONTENT

1. INTRODUCTION

Forest ecosystems act as an important part to accumulate the atmospheric CO_2 as organic carbon (C) in living and dead biomass. The total amount of carbon stocks in forest floor and terrestrial ecosystems are proportionately higher than the present level of carbon in the atmosphere. The major contribution of carbon dioxide emissions are fossil fuel combustion and deforestation of land area, which add about 8 Pg (1Pg= 10^{15} gram) carbon to the atmosphere each year, where only 3 Pg is added in the atmospheric carbon pool and the rest amount of is accumulating in the oceans and terrestrial ecosystem (Liski et al. 2003; Prentice et al. 2001). Carbon dioxide being a green house gas and its elevated concentration leads to global warming and climate change. The concentration level of CO_2 is highly variable and the increasing concentration of carbon dioxide in the atmosphere depends on various factors. Factors such as industrial revolution, population pressure, use of fossil fuels, land use changes etc. are the dominant source of carbon dioxide to the atmosphere (Malhi et al. 1999). According to fourth assessment report of IPCC (Intergovernmental Panel on Climate Change), the mean temperature increased 0.74°C between 1906 to 2005 and the rate of temperature will increased from 3 to 6 °C by 2100. The level of CO_2 increased from 367 ppm to 379 ppm in 2005 and continued to increase 1.5 ppm in every year (IPCC 2007; Malhi et al. 1999). However, it is important to bear in mind that huge amount of carbon has accumulated in the forest ecosystem during a long period of time, but because of the human disturbance, forest burning, deforestation and other ecological disturbances and misbalances in the forest ecosystems, results in the release of huge amounts of CO_2 into the atmosphere (Pregitzer & Euskirchen 2004). To combat with the global warming we must have to reduce the production of greenhouse gases and to find out the sink of greenhouse gases like CO_2.

Forest ecosystems are acting as atmospheric filters of CO_2 and the level of atmospheric CO_2 varies with the carbon balance in global forest ecosystems (Neilson et al. 2007). The net carbon balance in a forest ecosystem is a fine balance and controlled by two processes: (1) fixation of carbon dioxide and (2) release of carbon dioxide from the forest ecosystems. Fixation of CO_2 and processes of carbon acquisition are controlled by photosynthesis process, tree growth, forest ageing and soil carbon accumulation system, where processes of release of carbon dioxide from the ecosystem caused by respiration of living biomass, tree mortality, oxidation of soil carbon, degradation, deforestation, microbial decomposition of litter and disturbances processes (Malhi et al. 1999). Different tree parts are acting as the main source of the litter fall, which is the major contribution to input of carbon and nutrients to the soil.

Soil is an important factor for sequestering the atmospheric carbon dioxide and also has an important effect on the size of the organic carbon pool in the soil (Morisada et al. 2004). In order to estimates the potential changes in the soil carbon storage in the forest floor, one of the important factors is the estimate of the current amount of carbon in different soils (Liski & Westman 1995). Soil organic matter is one of the most important key components of any terrestrial ecosystem and has potential effects on the variation of abundance and composition of many processes that occur within the systems (Morisada et al. 2004). Due to increasing the carbon dioxide concentration into the atmosphere, an urgent issue needs to assess the feasibility of managing ecosystems to store carbon.

To estimate the possible changes on the carbon stocks in soils, it is important to establish a baseline to measure the current amount of carbon stocks in different forest floors and vegetation composition. The total net stock of soil organic carbon at regional, national or global scales is essential information for discussing the possible changes in carbon content or fluxes at each scale. For these purposes, regional and international studies are necessary (Liski & Westman 1997; Watson et al. 2000).

When it comes to the boreal forest ecosystems in Fennoscandinavia, there have been several studies focusing and analyzing on the measurement of carbon pools and fluxes due to large amounts of carbon contain at different scales (Dixon et al. 1994). Boreal forests are of particular interest because of their immense distribution and supposed to undergo the greatest climatically changes during the 21st century (Mukkunen & Heiskanen 2005). Boreal forest occupies a circumpolar belt in high northern latitudes, tundra and temperate forests and grasslands with a large land-area of about 13.7 million km^2 and contains a considerable high carbon density in these soils, around 15-20% of global terrestrial carbon reserves in the soils (Grace 2004; Larsen 1980; Liski et al. 1995; Post et al. 1982). Boreal forest also function as a source and sinks for nitrous oxide (N_2O), methane (CH_4) and in addition to carbon dioxide (CO_2) (Callesen et al. 2003). According to the figures presented by Dixon et al. (1994), 69% of the carbon is stored in the form of soil organic matter and the rest of 31% stored as living biomass. However, there is a significant difference between high latitude and temperate forest floors: in the boreal forest total 84% of carbon is stored in soil organic matter and only 16% of carbon stored in the active biomass, whereas in the tropics the carbon is divided more or less equally between the soil and vegetation pattern (Malhi et al. 1999). Due to climate changes and increasing the CO_2 into the atmosphere that also increasing the temperature can influences the total net amount of soil carbon stored in the boreal forest ecosystems in several ways. The current total amount of carbon stored in different soils is a key factor when calculating the changes in the soil carbon storage in response to climatic warming (Liski & Westman 1997). Finér et al. (2003) studied the changes in carbon pools in Finnish boreal forests and found significant effects of clear cutting on soil carbon pools and fluxes. Liski and co-workers suggested that the soil carbon sink was uncertain by 35% to 50% and the largest sources of this uncertainty were depend upon on the calculation of the litter production of different parts of trees and decomposition in soils. Studies have been conducted in Norway as well. For example, Clarke et al. (2007) studied the spatial variation in the concentration of dissolved organic carbon (DOC) pools in four Norway spruce stands. These studies showed a significant effect of stand age. Therefore knowledge on carbon storage and forest dynamics is very important for getting reliable information and obtaining more accurate results and predictions on carbon sequestration at the global and national scales. For improving our knowledge about the boreal soil carbon storage, more detailed information on the size of the soil carbon reserves and their spatial variability is needed (Liski et al. 1997).

The main aims of my study are:

1. To estimate the amount of carbon in the soil down to a depth of 15 cm in two forest sites and two adjacent open grazing lands.
2. To identify the organic top soil part of the soil profile and estimate the size of the carbon pool in this soil compartment individually.
3. To compare the size of the soil carbon pool between forested and non-forested open sites.

2. MATERIALS AND METHODS

2.1 Selection of the study sites

The study sites are two closed canopy forests and two open land areas located on the property of the Norwegian University of Life Sciences UMB in Ås community in the north-eastern part of Akershus County, south-eastern Norway (Fig.1 and 2).

Fig. 1: 55 years old forest stand and neighboring non-forest stand

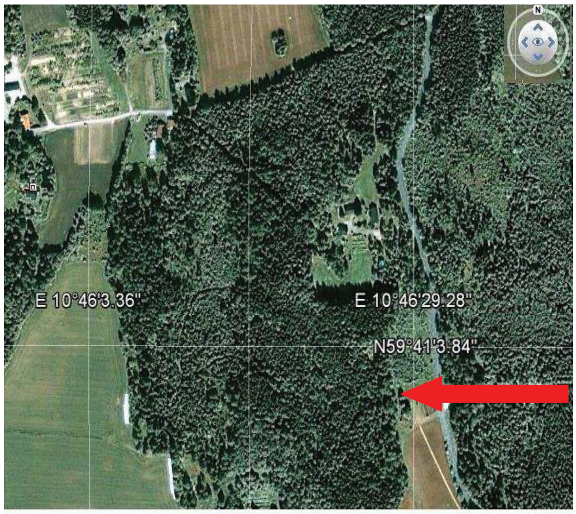

Fig. 2: 15 years old forest stand and adjacent non-forest stand.

The data presented were collected from 200 soil samples from four study sites. According to Meteorological data for Ås, the average monthly temperature is -9.5 °C in January and 16.9 °C in July, while the average annual temperature is 3.7 °C. The average precipitation per month varies from maximum 149 mm in August to minimum 11 mm in January; with a total annual average of 807mm. The two forest sites were dominated by Norway spruce (*Picea abies*) and there were some dead trees in the oldest forest site.


Fig. 3: Site-A (55 years old) Norway spruce (*Picea abies*) forest stand.

Site- A: A ca. 55 years old forest located 89 m above sea level, approximately 2.3 km northeast (59 º 40´ 38´´ N, 10 º 45´ 47´´E) of the campus at the Norwegian University of Life Sciences (UMB). The forest is planted on a former open grazing land and consists mainly of Norway spruce (*Picea abies*). The ground vegetation is dominated by *Vaccinium myrtillus* and the following vascular plant species are common: *Anemone nemorosa, Deschampsia flexuosa, Droypteris expansa, Hieracium sylvaticum, Lactuca muralis, Maianthemum bifolium, Melampyrum sylvaticum, Oxalis acetosella, Rubus idaeus, Sorbus aucuparia, Stellaria nemorum,* and *Trientalis europaea*. The bryophyte flora is dominated by species like *Pleurozium schreberi* and *Hylocomium splendens* (Mikael Ohlson, personal communication).


Fig. 4: Non-forest stands adjacent to 55 years old forest stand.

Site- B: An open grazing land directly neighboring the south-east border of the 55 year old spruce forest (***Site- A***). Both study sites (55 years old forest + adjacent non-forest land) are referred to as Location A. The ground vegetation in this area is dominated by *Deschampsia caespitosa* and *Poa pratensis.* Other typical species are: *Achillea millefolium, Lepidotheca suaveolens, Polygonum aviculare, Plantago major, Rumex longifolius,Tripleurospermum perforatum and Trifolium repens* (Mikael Ohlson, personal communication).

Fig. 5: Site- C (15 years old) Norway spruce (*Picea abies*) forest stand.

Site-C: A ca. 15 years old Norway spruce forest stand as referred to as Study site C, located 117 m above sea level approximately 2.5 km northeast (59 º 41′ 04′′ N, 10 º 46′ 28′′E) of the UMB campus. The forest is planted on former open grazing land and is partly wet due to a small narrow ditch that is passing inside the forest area. Besides Norway spruce, the vegetation consist mainly of *Sorbus aucuparia, Fraxinus excelsior, Rubus idaeus, Sambucus racemosus, Salix caprea, Betula pubescens, Urtica dioica, Deschampsia caespitosa, Lysimachia vulgaris, Filipendula ulmaria, Poa pratensis* and *Dactylis glomerata* (Mikael Ohlson, personal communication).

Fig. 6: Non-forest stands neighboring to 15 years old forest stand.

Site-D: An open grazing land neighboring the southern side of the young spruce forest stand at site C. Both study sites C and D are together demonstrated as Location B. The ground vegetation is rather species-rich with *Deschampsia caespitosa, Alopecurus pratensis, Elytrigia repens, Dactylis glomerata, Agrostis capillaries, Poa pratensis, Filipendula ulmaria, Trifolium hybridum, Rumex longifolius, Galium mollugo, Artemisia vulgaris, Cirsium arvense, Cirsioum palustre, Hypericum maculatum, Tanacetum vulgare, Chrysanthemum leucanthemum, Vicia cracca, Anthriscus sylvestris and Achillea millefolium* being common in the area (Mikael Ohlson, personal communication).

2.2 Soil sampling

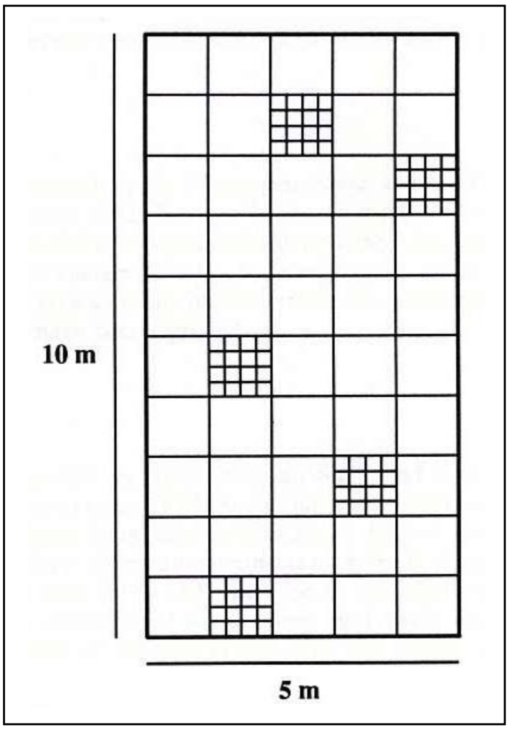

Fig. 7: Design of the selection of data sampling positions by a restricted random procedure.

Ten macro sample plots, sized 5 × 10 m, were placed in each of the four study sites. The macro sample plots were located subjectively in order to represent the variation along ecological gradients in aspects, nutrient conditions, light supply, topographic conditions, soil moisture etc. Five sampling positions within the macro sample plot were determined by random, i.e. a restricted random sampling procedure (see e.g. Økland 1996 for further information). The soil samples were collected from the center of the selected 1 × 1 m plot. A total of 50 samples were taken from each study site. Soil and bryophyte samples were collected by using a steel cylinder (diameter 5.8 cm). First, the thickness of the organic top soil was measured and then was the total length (depth) of the soil core measured. After was the entire soil profile in its natural form put in a carefully marked plastic bag for transportation to the laboratory (Liski et al. 1997). The reason for using the plastic bag is that will not soak the moisture of soil samples. Soil cores included the entire layer of the organic top soil and the cores were intended to represent a soil depth of at least 15 cm. However, a few cores were shorter due to shallow soil and occurrence of rocks and boulders. Here, the motivation for sampling of the 15 cm top-soil-layer is that this soil layer is rich in carbon and that this carbon pool is biologically reactive (Finér et al. 2003). Totally, 200 soil samples with vascular plants, and bryophytes were collected from the study sites for this analysis.

2.3 Laboratory analysis

The organic and mineral horizons of the soil cores were separated carefully to avoid contamination between the layers (Liski and Westman, 1997b).The vegetation from the top of the soil cores was removed and bryophytes and vascular plants were stored separately. I also removed large tree roots from the organic and the mineral soils and placed organic soil, roots from the organic soil, mineral soil and roots from the mineral soil in separate paper bags. All samples were than dried to constant weight at 105°C (-overnight) and stored them for further analysis.

Loss on ignition: The percentage weight loss on ignition gives a robust estimate of the organic content in the soil. Generally, percentage loss on ignition values showed an inverse relationship with percentage dry weight values. From the dried (overnight at 105 °C) soil samples, 3 g was taken from each samples and put in crucibles that were placed in the furnace and kept at 550 °C for 2 hours. When the samples had cooled slightly, they were placed in a desiccator and allowed to cool fully before they were re-weighted. The percentage of the dry weight lost on ignition was then calculated.

2.4 Data analysis

A carbon content of 50% was assumed for the organic soil components and all living components such as field layer vegetation, branches, bryophytes, roots, living trees, etc. (Chapin et al. 2002). In the analyses I have calculated the size of the soil carbon pool on both a volume and an area basis, i.e. g carbon per liter soil and g carbon per m^2 forest ground. Many samples contained no organic soil, for instance of the sampling spot was a rock outcrop or root at the soil surface etc. The carbon content in different soil was calculated with the following formula, $C = \{W*LOI (\%)*0.5\}/A$, where W= soil dry weight, LOI= loss on ignition percentage, A= soil area. Simple summary statistics like mean, standard deviations, degree of freedom, F value and p values were calculated for the raw data and are presented in the tables. In cases where mean values are presented in the text, the precision of the mean is indicated by ± 1 SD of the mean. ANOVA and two sample t-tests were used for the testing the differences in soil carbon content between the location sites and also within the location. In order to adjust for differing volumes of the collected samples, the thickness of the samples was also included in this analysis. ANOVA and t-tests were also used for the analysis of the effects of depths on carbon content. All calculations were done by using the SPSS software.

3.RESULTS

Table 1: ANOVA- test of differences of carbon content (gm^{-2}) between four study sites.

Carbon content	Site-A(55 years old forest)	Site-B (Adjacent to site A)	Site-C (15 years old forest)	Site-D (Adjacent to site C)	Average for all sites	F	P
Organic soil*	1322 ± 369	0.0	142 ± 59	664 ± 230	532 ± 564	372.89	<.0001
Mineral soil	1692 ± 553	1826 ± 566	713 ±152	1239 ± 231	1368 ± 604	72.11	<.0001
Total in soil	3014 ± 785	1826 ± 566	855 ± 180	1903 ± 327	1900 ± 923	144.78	<.0001
Bryophytes*	172 ± 130	0.0	122 ± 160	257 ± 388	138 ±237	11.946	<.0001
Vascular plants	110 ± 98	37 ± 69	63 ± 87	4 ±23	54 ± 84	17.90	<.0001
Total in vegetation	283 ± 178	37 ± 69	187 ± 180	261 ± 388	192 ± 251	11.20	<.0001
Total carbon	3297 ± 828	1864 ± 575	1043 ± 233	2164 ± 518	2092 ± 993	129.85	<.0001

*All values are mean ± SD and significant level measure at $p<0.05$. * The test is not allowed to express significant value due to the absence of organic soil and bryophytes in the site B.*

Table 1A: ANOVA-test of differences of carbon content on a soil volume basis (g/l) between four study sites.

Carbon content	Site-A (55 years old forest)	Site-B (Adjacent to site A)	Site-C (15 years old forest)	Site-D (Adjacent to site C)	Average for all sites	F	P
Organic soil*	29 ± 8	0.0	17 ±6	26 ±8	18 ±13	220.37	<.0001
Mineral soil	10 ±3	8 ±3	3 ±0.7	6 ±1	7 ±3	82.92	<.0001
Total in soil	39 ±10	8 ±3	21 ±7	32 ±9	25 ±14	176.18	<.0001

*All values are mean ± SD and significant level measure at $p<0.05$. * The test is not allowed to express significant value due to the absence of organic soil in the site B.*

The carbon content in the soil varied significantly among the four study sites (Table 1). Among the study sites, mean soil carbon content was highest in site A and lowest in site C. The mean carbon content was higher in the mineral soil than in the organic soil on an area basis. Carbon content in the mineral soil was higher in site B compared to site A, C and D. The percentage value showed that site B content (33%) carbon in mineral soil, where site A, C and D content (19%), (27%) and (21%) respectively (Figure 8). Carbon content in the organic soil was higher in site A in comparison to all other sites. An organic top soil layer lacked in Site B, which explain the zero value for the organic soil in site B (Table 1). Carbon content in the vegetation varied considerably across the study sites. The carbon content in the vegetation was significantly higher in the site A, but lower in site B (Table 1). The carbon content in the bryophytes varied significantly between the study sites and there were more carbon in the bryophytes than in the vascular plants. The total mean carbon content in the soil down to a depth of 15 cm was 2092 ± 993 gm^{-2} (Table 1). The total mean carbon content, expressed on a volume basis, was significantly higher in site A than in any other of the study sites, where site B had the lowest content per volume unit of soil (Table 1A). The content of carbon per volume unit of the organic top soil was significantly higher than in the underlying mineral soil. The forest soil in site A had most organic top soil and thus more carbon in this soil layer than sites B, C and D (Table 1A). In terms of percentage of carbon value site A forest content higher (39%) than site B, C and D with (22%), (13%) and (26%) respectively (Figure 8).

Table 2: Two sample test of differences of carbon content (gm^{-2}) in the soil of forest and non-forest at the location A.

Carbon content	Site-A (55 years age old forest)	Site- B (Non-forest)	Total (Site A and B)	t	P
Organic soil*	1322 ± 369	0.0	661 ± 713	9.26	<.0001
Mineral soil	1692 ± 553	1826 ± 566	1759 ± 561	31.36	.234
Total in soil	3014 ± 785	1826 ± 566	2420 ± 905	26.72	<.0001
Bryophytes*	172 ± 130	0.0	86 ± 126	6.85	<.0001
Vascular plants	110 ± 98	37 ± 69	74 ± 92	8.02	<.0001
Total in vegetation	283 ± 178	37 ± 69	160 ± 182	8.76	<.0001
Total in Location A	3297 ± 829	1864 ± 575	2580 ± 1011	25.52	<.0001

*All values are mean ± SD and significant level measure at $p<0.05$. * The test is not allowed to express significant value due to the absence of organic soil and bryophytes in the site B.*

Table 2A: Two sample test of differences of carbon volume (g/l) in the soil of forest and non-forest at the location A.

Carbon content	Site-A (55 years old forest)	Site-B (Non-forest)	Total (Site A and B)	t	P
Organic soil*	29 ±8	0.0	15 ±16	9.35	<.0001
Mineral soil	10 ±3	8 ±3	9 ±3	30.98	.018
Total in soil	39 ±10	8 ±3	24 ±18	13.93	<.0001

*All values are mean ± SD and significant level measure at $p<0.05$. * The test is not allowed to express significant value due to the absence of organic soil in the site B.*

In location A, the mean carbon content in the soil varied significantly between the forest and open grazing land sites as mean soil carbon content was considerably higher in the site A than site B (Table 2). Because the organic top soil components was fully missing in site B, no carbon was found in the organic soil at the site B forest floor. The carbon content in the mineral soil did not differ between the two sites. However, the carbon content in the vegetation was significantly higher in the forest (55 years old) than in the open grazing land. The mean carbon content in vascular plants was significantly higher in site A than site B, whereas bryophytes were fully missing in site B area. Whenever I compared the variations of carbon content between two sites I found that carbon content in site A was significantly higher than in site B (Table 2).

In the location A, the mean carbon content per volume unit of soil varied significantly between the study site A and B (Table 2A). The organic top layer of the forest soil in site A contained more carbon than the mineral soil (no organic top soil layer was present in site B). In mineral soil, the carbon content was almost similar in both study sites, where site A had a little bit higher value than the site B forest soil. However, the mean carbon content per volume in the soil was higher in the site A forest than site B (Table 2A).

Table 3: Two sample test of differences of carbon content (gm^{-2}) in the soil of forest and non-forest at the location B.

Carbon content	Site-C (15 years old forest)	Site-D (Non-forest)	Total	t	P
Organic soil	142 ± 59	664 ± 230	403 ± 311	12.96	<.0001
Mineral soil	713 ± 152	1239 ± 230	976 ± 328	29.74	<.0001
Total in soil	855 ± 180	1903 ± 327	1379 ± 588	23.44	<.0001
Bryophytes	121 ± 160	257 ± 388	189 ± 303	6.24	.025
Vascular plants	66 ± 87	4 ± 23	35 ± 71	4.97	<.0001
Total in vegetation	187 ± 180	261 ± 388	224 ± 303	7.39	.227
Total in location B	1043 ± 233	2164 ± 518	1603 ± 690	23.21	<.0001

All values are mean ± SD and significant level measure at $p<0.05$.

Table 3A: Two sample test of differences of carbon content on a soil volume basis (g/l) in the soil of forest and non-forest at the location B.

Carbon content	Site-C (15 years old forest)	Site-D (Non-forest)	Total	t	P
Organic soil	17 ±6	26 ±8	22 ±8	26.45	<.0001
Mineral soil	3 ±0.7	6 ±1	5 ±2	27.04	<.0001
Total in soil	21 ±7	32 ±9	27 ±10	28.84	<.0001

All values are mean ± SD and significant level measure at $p<0.05$.

In location B, the carbon content in the soil significantly varied between the study sites (Table 3). The mean soil carbon content was higher in the mineral soil than organic soil. Carbon content in the mineral and organic soil was higher in the site D than in the site C forest soil. The total carbon content in soil was significantly higher in the site D than site C with 1903 ± 327 gm^{-2} and 855 ± 180 gm^{-2} respectively. The carbon content in the vegetation varied insignificantly across the study sites (forest vs. non-forest), but higher in the site D (non-forest) than site C (forest). The carbon content in the bryophytes was higher in the site D than site C, where for vascular plants; the carbon value was significantly and comparatively higher value in the site C forest floor than non-forest floor. The overall study revealed that, the average carbon content in the location B was higher at the site D than site C area with indicated significant variation in the carbon proportion between the forest and non-forest stand (Table 3).

The content of carbon per soil volume unit the total mean value was significantly higher in site D compare to the site C forest soil (Table 3A).

Table 4: Two sample test of differences of carbon content (gm^{-2}) between two locations.

Carbon content	Location A	Location B	Total in all locations	t	P
Organic soil	661 ± 713	403 ± 311	532 ± 564	13.34	.001
Mineral soil	1759 ± 561	976 ± 328	1368 ± 603	32.04	<.0001
Total in soil	2420 ± 905	1379 ± 588	1899 ± 923	29.09	<.0001
Bryophytes	86 ± 126	189 ± 303	138 ± 237	8.21	.002
Vascular plants	74 ± 92	35 ± 71	54 ± 84	9.16	.001
Total in vegetation	160 ± 182	224 ± 303	192 ± 252	10.79	.071
Total in study area	2580 ± 1011	1603 ± 690	2092 ± 993	29.79	<.0001

All values are mean ± SD and significant level measure at p<0.05.

Table 4A: Two sample test of differences of carbon content on a soil volume basis (g/l) between two locations.

Carbon content	Location A	Location B	Total in all locations	t	P
Organic soil	15 ±16	22 ±8	18 ±13	19.80	<.0001
Mineral soil	9 ±3	5 ±2	7 ±3	30.90	<.0001
Total in soil	24 ±18	27 ±10	25 ±14	25.90	.156

All values are mean ± SD and significant level measure at p<0.05.

The mean differences of carbon content in the soil between two locations varied significantly and higher in the location A compared to location B (Table 4). The average soil carbon content was higher in the mineral soil than organic soil. Location A content higher percentage of carbon value in both organic and mineral soil than the location B. The variation of carbon content in bryophytes and vascular plants across the study sites was significant. Location B content higher percentage of carbon in bryophytes than location A, where carbon in vascular plants was higher in the location A forest floor. The overall carbon content across the study locations varied significantly, but higher in the location A than location B (Table 4). When all components are considered together (soil and vegetation samples), location A showed higher percentage of carbon amount (62%) compared to the location B (38%) forest site (Figure 8).
The mean carbon content in the soil volume did not differ significantly between the location A and B. Location B content higher percentage of carbon volume than location A forest soil (Table 4A). In the both locations, organic soil content higher percentage of carbon than mineral soil.

Table 5: Two sample test of differences in soil carbon content (gm^{-2}) between two forests of different age.

Carbon content	Site-A (55 years old forest)	Site-C (15 years old forest)	Total in all forest	t	P
Organic soil	1322 ± 369	142 ± 59	732 ± 648	11.29	<.0001
Mineral soil	1692 ± 553	713 ± 152	1203 ± 636	18.90	<.0001
Total in soil	3014 ± 785	855 ± 180	1935 ± 1224	15.81	<.0001
Bryophytes	172 ± 130	121 ± 160	147 ± 147	9.99	.084
Vascular plants	110 ± 98	66 ± 87	88 ± 95	9.26	.019
Total in vegetation	283 ± 178	187 ± 178	235 ± 185	12.73	.009
Total in study area	3297 ± 829	1043 ± 233	2170 ± 1284	16.89	<.0001

All values are mean ± SD and significant level measure at p<0.05.

Table 5A: Two sample test of differences in soil carbon content (g/l) between two forests of different age.

Carbon content	Site-A (55 years old forest)	Site-C (15 years old forest)	Total in all forest	t	P
Organic soil	29 ±8	18 ±6	23 ±10	25.33	<.0001
Mineral soil	10 ±3	3 ±0.7	7 ±3	16.86	<.0001
Total in soil	39 ±10	21 ±7	30 ±13	24.10	<.0001

All values are mean ± SD and significant level measure at p<0.05.

The mean carbon content differed significantly between the two different aged forest stands (Table 5). The total mean soil carbon content was higher in the 55 years old forest soil compared to 15 years forest soil. Mineral soil exhibited higher carbon content than organic soil on an area basis. Soil carbon in mineral and organic soil was significantly varied in site A and C. The average carbon content between two sties varied significantly and higher in the 15 years forest stand than the 55 years stand. The carbon content in the vegetation was significantly higher in the site A compared to the site C. The carbon content in the bryophytes varied insignificantly between the study sites. Site A forest floor contained more carbon in bryophytes than site C forest floor. For vascular plants, the carbon value was significantly observed in all study sites and also higher in the site A forest floor.

The total mean carbon content in the organic and mineral soil differed significantly between the site A and C and showed higher percentage of carbon in site A forest soil than site C forest soil. Organic soil content significantly higher percentage of carbon than mineral soil (Table 5A).

3.1 Distribution of Carbon Percentage

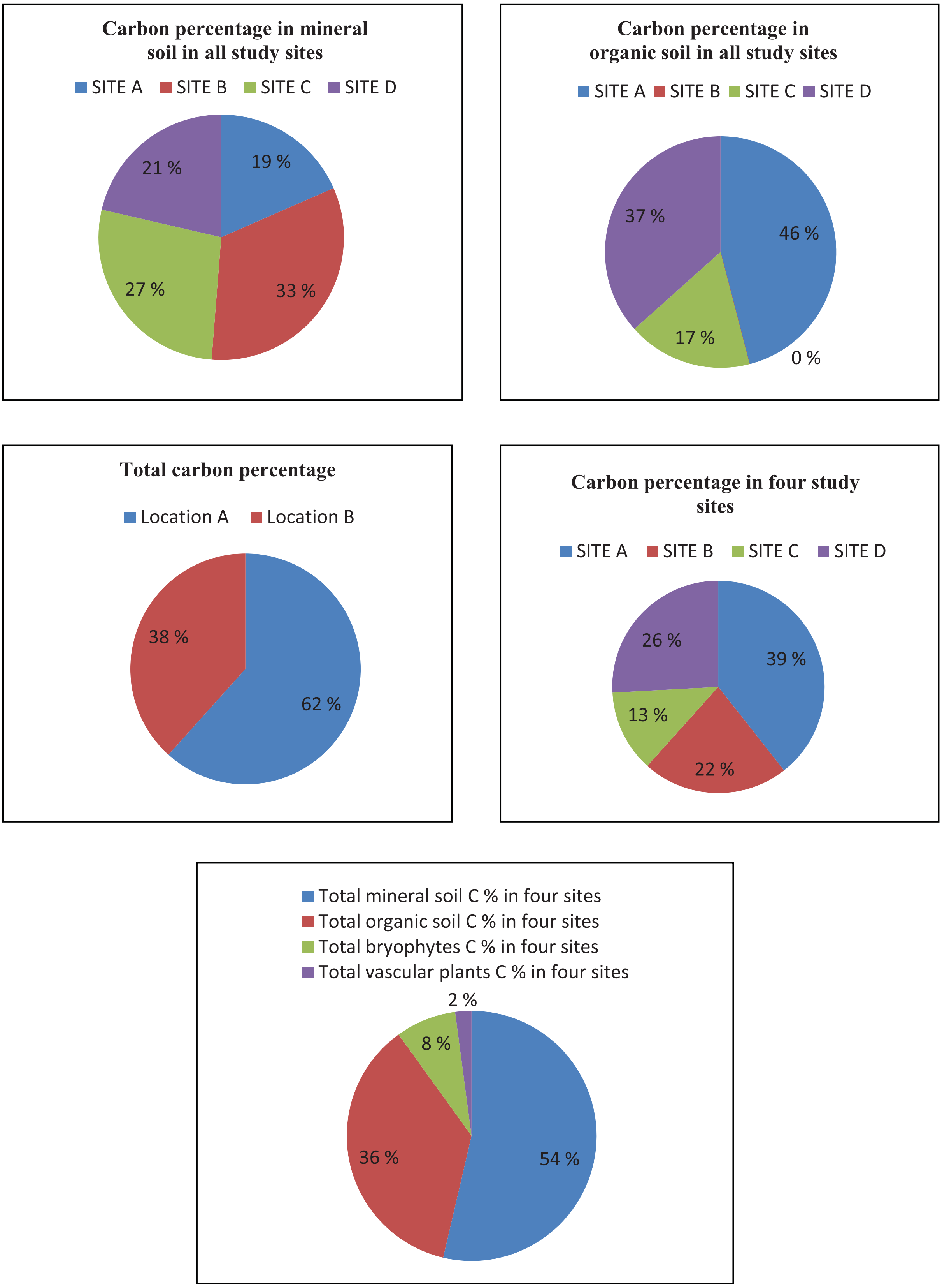

Fig. 8: Distribution of carbon percentage across the four study sites.

4. DISCUSSION

Boreal forests contain a large quantity of organic carbon in different types of soils and the percentage of carbon content varies within the boreal zone. However, more detailed and accurate knowledge is needed to estimate accurately soil C reserves in different parts of the boreal forests as well as in boreal forests on the whole (Liski et al. 1995). In the discussion I will focus on the following main conclusions that I draw from my results.

4.1 Amount of carbon in all study sites

The total average amount of carbon in the studied compartments across all study sites was 2092 ± 993 g/m^2. This value is considerably lower than other studies. For example, Pregitzer & Euskirchen (2004) who studied five age classes of boreal forests, found an average of 14.3 kg/m^2 carbon in the study area. Another study conducted by Finér et al. (2003) in an old growth mixed coniferous forest in eastern Finland where Norway spruce (*Picea abies*) was dominated species, had an average amount of 14.4 kg/m^2, which is a considerably higher amount of carbon than in my study. According to Liski et al. (1995), 68% of carbon was found in 1m depth mineral soil down and 28% was accumulated in the organic top layer soil, where my study revealed that 19%, 33%, 27% and 21% of carbon in mineral soil at site A, B, C and D respectively with a depth of 15 cm and 46%, 0%, 17% and 37% of carbon in organic top soil layer at site A, B, C and D respectively (Figure 8). The main reason for the difference in carbon value compare to other studies is that the resulted value of carbon in my study sites was in a small volume of soil (15 cm deep samples compare to 100 cm deep samples).

4.2 Soil organic carbon (SOC)

The total mean value for SOC across all study areas was 1900 g/m^2 with a range from 855 to 3014 g/m^2. Site B and D mean carbon values were very close to some other findings. For instances, Liski et al. (1997) studied in a coniferous forest in southern Finland found a mean value of 1.2 kg/m^2 are close to the mean soil carbon value of my results. Another study reported by Kolari et al. (2004) in different Scots pine aged forests in Southern Finland had an average carbon mean values between 1.2 and 1.8 kg/m^2 showed almost close result of my findings. Different aged Norway spruce (*Picea abies*) stands in southern Norway showed similar results, for example, a study done by Clarke et al. (2007) showed mean SOC values ranging from 2.3 kg/m^2 to 5.2 kg/m^2 where my study sites showed mean SOC values ranging from 855 g/m^2 to 3015 g/m^2. According to some studies the main factors that influence the total amount of soil organic carbon in the first 100 cm is the soil texture and climatic variation of forest structure (Kleja et al. 2008). Another factors such as precipitation, temperature, aspect, topography, soil parent material, soil age, carbon pools, vegetation and climate also showed a relationship to response C density in soil (Callesen et al. 2003; Liski et al. (1995). My study sites were situated quite close to each other and the climatic conditions and soil types were similar. So it can be say that regional ecological factors are involved in SOC variation. It is really difficult to explain what factors are associated that caused the significant variation across sites and the higher percentage of carbon amount in the soil at site D. My findings showed that site C (15 years old plantation) contained lower percentage of SOC than site-D (non-forest stand). The possible reason could be that, in site-C area, a small ditch was passing into the forest area, creates shallow soils and affected the root biomass and site hydrology that produces low productivity and reduces the potential overestimation can be a factor for this result. Some studies suggested that latitude can be a factor for the variation of carbon density in the forest floor. Reed & Nagel (2003) found that, the latitude factor is effective for calculating on the larger geographical range areas, where my study sites were quite close to each other and this application cannot be applied in my sites.

4.3 Field layer vegetation and bryophytes

The field layer vegetation and bryophytes for some studies was carried out in *Vaccinium myrtillus* type and bottom layer with *Pleurozium schreberi* type, similar to these study areas. Generally, the field layer vegetation and bryophytes did not contribute more percentage of carbon to the total ecosystem. But it may play an important role in many ecosystem processes. Finér et al. (2003) found that field layer vegetation (0.04 ±0.01 kg/m^2) and bryophytes (0.08 ±0.01 kg/m^2) contributed less than 2% of carbon pools, where my study showed high percentage of carbon in total field layer vegetation with the average of (192 ±251 g/m^2) and in case of bryophytes and vascular plants with (138 ±237 g/m^2) and (54 ±84 g/m^2). During the field survey, location A had higher percentage of vegetation abundance than the other sites. Another study done by Reed et al. (2003) found that the field layer vegetation and bryophytes contribute a small part of the total ecosystem of carbon pool. In comparison to other components of the research variables, the total percentage of understory vegetation is relatively small, only 2-8% of the total carbon pools, but it is still not negligible (Figure 8). This small percentage can play an important role in many ecosystem processes, such as, nutrient and carbon cycling in forest floor. The large amount of *Vaccinium myrtillus*, herbs and grasses has a higher rate of decomposition than the conifers and also has an important interference effects that can also interfere with biomass accumulation process between components such as tree, field layer and bottom layer species. This means that the field layer vegetation together with bryophytes is likely to have a major important part of the total carbon pool in boreal forest ecosystems.

4.4 Depth effect

The depth effect turned out to be significant for carbon content, where a decreasing carbon trend was observed. Some studies found positive significant effects on carbon content with deeper soil profiles. These have that carbon is rich in organic top-soil and the less carbon found in underlying mineral soil. For instances, the global data set by Jobbagy & Jackson (2000) showed that up to 3 meters and 20 cm intervals organic carbon content diminishing constantly from 0-1 meter with the following distribution 50%, 25%,13%,7% and 5%. Pregitzer et al. (2004) also noticed in his study that carbon concentration was decreasing with increasing soil depth. Another study done by Callesen et al. (2003) showed a decreasing soil organic carbon (SOC) trend in well drained soil (up to 100 cm) with increasing soil depth from four Nordic countries. However, my result showed similar carbon trend from the previous studies. With increasing thickness of the soil volume, the amount of carbon content was decreasing from organic top soil to deeper mineral soil. SOC was decreasing in terms of soil depth or thickness, organic top soil content more C than mineral soil. In Finland, Havas & Kubin (1983); Mälkönen (1975) studied on the density of organic carbon, no deeper than 60 cm in mineral soil has been analyzed by the loss-on-ignition method. These studies were not very useful when calculating the total amount of organic carbon in the soil. First of all, up to 60 cm soil layers contained large quantities of organic carbon and secondly, conversion of loss-on-ignition method was problematic in mineral soil samples. However, my results showed that up to 15 cm soil layers compare to thickness in different layers, organic soil contained higher amount of soil carbon. This could be a significant effect may be due to the narrow range of depths studied only 0-15 cm.

4.5 Forest age

Forest age can be a variation factor for total carbon concentration. Some studies found that forest stand age has a positive correlation factor for calculating soil carbon (Ilvesniemi et al. 2002; Pregitzer et al. 2004). According to Birkeland (1984), soil carbon storage increases rapidly for first tens or hundreds of years and thereafter this increase slows down gradually, and the storage reaches at equilibrium stage at an age ranging from as little as 200 years to some 10000 years, depending on the conditions of forest structure and other climatic factors. Based on those findings the carbon storage in the selected soil layer at the research sites is at equilibrium.

The average amount of carbon in different forested sites varied from 3297 g/m^2 (55 years old forest) to 1043 g/m^2 (15 years plantation) and the total amount of C in all aged forest was 2170 g/m^2 for both aged forest sites. Compare to other studies, these stands showed a lower value. For example, Finér et al. (2003) found an average of carbon value 10.7 kg/m^2 with an old-growth (140 years to 170 years), mixed forest in eastern Finland. Another study done by Kleja et al. (2008) in three 40 year old Norway spruce stands along a north-south climatic gradient in Sweden showed carbon variation from 4.6 kg/m^2 in the north to 8.0 kg/m^2 in the south.

A positive trend was observed between the carbon content and forest stand age. For example, in the site A (55 years old) forest stand counted nearly about 39% of all the carbon found, while site C (15 years old stand) counted 13% of carbon at the site (Figure 8). According to Kolari et al. (2004) study, higher percentage was observed for the oldest stand. Pregitzer et al. (2004) also noted that with the increasing living biomass with increasing age, increased carbon percentage in boreal forest. Different study factors may perhaps be explained these differences in the results. While many studies represented a large-scale research on boreal forest with different forest stands and locations, my research was based on smaller scales with fairly small geographical area.

4.6 Difference in carbon distribution between location A and B with regard to the amount of carbon

The main goal for the two locations was to see how the different aged plantation influence on the amount of carbon, and to see if I could find any significant trends in carbon distribution between location A and location B. The difference between location A and B across all study sites including the amount of carbon in soil, root, and vegetation was highly significant. It should be noted that, location A yield more precise result regarding the average amount of carbon content is soil as compared to location B forest stand (Figure 8). One possible reason could be, in the location- A at the site- B forest has no organic soil samples and site –A forest content more mature forest tree and forest floor than location B, where location B has more soil sample data across the entire study sites and at the site C, forest floor was wet in some parts. In the site-B forest floor, I found stones in the soil that could be affect the soil carbon balance, net primary production and decomposition of organic matter in soil. The stones should reduce the soil carbon density Liski et al. (1997). However, some more explanations for the observed results between the two study location sites could be done.

If all components are considered together (soil and vegetation samples), location A showed highest values for across all study sites, while location A had the highest amount of carbon in terms of volume measurements. All zeros ("no soil" cases) were included in the analysis leading to these results.

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