Variability in soil climate and respiration on managed timber stands: A case study in southwest Oregon

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ABSTRACT

Thinning of forested lands and timber stands in the Pacific Northwest have taken place for centuries with a limited understanding of how the alterations may affect ecosystem functions. The goal of this study was to examine the soil climate and microbial activity on a seasonal timescale of thinning practices examined at different stages of succession. Two timber stands in Southwestern Oregon within the Grayback Creek Watershed had identical forest management techniques separated by a 10-year treatment interval (40% variable density thinning). Field methods and equipment measured canopy coverage, soil moisture and temperature at 3 depths (5, 15, 30 cm), as well as snow and precipitation events. Laboratory analysis included particle size analysis (PSA), determination of total %C and %N, and CO_2 respiration. The least diurnal flux occurred at the deepest (30cm) and the greatest temperature flux near the surface (5cm). The covered stand showed a smaller magnitude of diurnal flux compared to the thinned stand ($\pm3°C$ and $\pm7°C$ respectively). The thinned stand had twice as much (10.8%) water by volume at the 5cm level compared to the covered stand (5.2%). The thinned stand reached 40% water content (θ_s) throughout the profile after the first snowmelt, the covered stand rarely approached that level at any depth and time. CO_2 respiration, total carbon, and total nitrogen were significantly less on the thinned site compared to the covered site (12 v 45 ppm CO_2 at the surface, 2 v 5% carbon, 7 v 20% total nitrogen respectively). The lack of vegetation density (therefore decreased transpiration demands) on the thinned site may account for the differences between (1) water content differences at the peak of the dry season, (2) differences in the magnitude of diurnal flux, (3) and amount of precipitation required to reach θ_s. The CO_2 respiration differences can be attributed to the covered understory vegetation significantly adding more organic matter for microbe decomposition compared to the relatively bare ground on the thinned stand.

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INTRODUCTION

In the course of human history, we have modified or completely changed the land use in forested areas with limited understanding of how alterations may affect ecosystem functions (Tanaka and Hashimoto, 2006). Especially in the Pacific Northwest (PNW), water required for agriculture, human consumption, and timber products for infrastructure development are derived from forested ecosystems. Thus, it is imperative that land managers understand how forest operations affect hydrologic functions of forested ecosystems and how these changes may affect the microbial communities providing nutrients for fiber growth. The dichotomy between potential wood production and ecological values in forest settings over multiple centuries are inadequate (Busing and Garman, 2002). Silviculture regimes, including length of rotation and type of prescription, can achieve a wealth of short-term objectives. However, great difficulty has risen in promoting old-growth characteristics such as species diversity and vertical canopy heterogeneity (Hale et al., 1999; Busing and Garman, 2002). Forest management is difficult because the life cycle of trees surpass that of any human; but an understanding of water transport and soil climate (defined in this paper as soil temperature and soil water content) can provide a deeper understanding of ecosystem functions and stand development (Warren et al., 2005). Understanding how soil climate differs after stand manipulation is crucial for the health and sustainability of our national forests.

Water stresses from droughts are a significant factor for seedling regeneration and anthropogenic climate change may exacerbate this issue in the future (Livingston and Black, 1987; Mote et al., 2003). Especially when trees are young and lack a prominent taproot, the soil water content in the upper horizons greatly influences seedling survival. The establishment of coniferous seedlings is greatest in the largest gap sizes and least in areas of dense canopies due to

differences in sunlight and possibly competition for water (Grey and Spies, 1996). Hydraulic

redistribution by older conifers is an important mechanism to provide water near the surface

during the summer months; but the amount of water is very difficult to quantify over seasonal

timescales (Brooks et al. 2002). Understanding seasonal variation in soil climate and responses

to precipitation events following the dry season in managed stands can provide a comprehensive

foundation for management actions.

Seasonal variations in soil climate are expected and management prescriptions often

create canopy gaps promoting understory and sub-surface heterogeneity (Grey et al., 2002). The

establishment of understory vegetation is a factor of litter depth, soil moisture, and amount of

light intercepted at the surface undoubtedly influenced by the extent of canopy coverage (North

et al., 2005). Gap sizes in forests influence the quantity of sunlight reaching the forest floor, and

significantly affect the magnitude of soil temperature flux. Clear cutting has been shown to

increase mean annual surface soil temperatures up to 3.2°C there by significantly affecting

biological activity in the upper soil horizons (Hashimoto and Suzuki, 2003). Conifer seedling

growth is greatest between 18-20°C and root elongation is stunted at temperatures below 8°C

(Anderson et al., 1986). Microbial biomass, like understory vegetation, is function of the type

and quantity of substrates available as well as the soil climate dictated by the quantity heat and

water present in the soil (Skopp et al., 1990).

Soil temperature greatly affects microbial biomass, as measured by CO_2 respiration.

Many researchers have found increasing temperatures are directly correlated to increases in

microbial respiration (Pietikainen, 2005; Paul and Clark, 1996; Lloyd and Taylor, 1994; Chen et

al., 2000). Carbon dioxide (CO_2) is a molecule that provides chemical energy to vegetation and is

a product from microbial respiration. The importance of CO_2 in the decomposition cycle and the

ease that it can be detected, provide an ideal compound to quantify microbial biomass (Haney et al., 2008). Singh and Gupta (1977) found greater microbial biomass, measured by CO_2 respiration, is related to a greater degree of decomposition.

Litter quality carries a direct effect on the rate of decomposition. Higher quality components, which are considered labile, will break down first. Decomposition rates will increase, but the rate of decomposition will decrease over time due to the remnants of recalcitrant substances (Kuers and Simmons, 2005). The labile substances, with low molecular weight, are considered readily available C substrates and can increase nutrient cycling frequency (Sikora and McCoy, 1990; Townsend et al., 1997). The microbial-mediated mineralization of organic compounds from organic matter to inorganic, plant available forms provides vital sources of energy for plant growth and photosynthesis (Uchida et al., 2010). Effectively closing the nutrient cycle, plants die and microbial populations decompose the organic materials and respire CO_2 in the process. Microbial CO_2 respiration is integral for predicting decomposition of organic materials, and understanding the temperature effects on CO_2 respiration may be incredibly important for climate change modeling.

The goal of this study was to examine the differences in soil climate and microbial activity on seasonal timescales as influenced by variable thinning practices on two stands. The soil's response to the first rain event, behavior of soil upon reaching saturation, and the magnitude of diurnal flux between the stands will be evaluated. The influence of soil temperature, soil organic matter (SOM) quantity, and trends in soil CO_2 respiration at increasing depth will also be examined.

MATERIALS AND METHODS

General site characteristics

The study site is located in southwestern Oregon along the Siskiyou mountain range approximately 80 km south of Grants Pass within the Rogue River-Siskiyou National Forest and remains tectonically active (Bishop, 2010)(Fig. 1). The majority of upper Grayback watershed is underlain by upper Jurassic and lower Cretaceous felsic intrusive rocks between granitic to gabbro compositions, although diorites are the most common (USGS, 1961). The soils within the study area are described as coarse-loamy, mixed, frigid Dystric Xerochrepts (Soil Survey Staff) (Appendix- Part I). Other site characteristics differed greatly due to the timing of management actions.

Two timber stands within the Grayback Creek Watershed were chosen because of identical forest management techniques separated by a 10-year treatment interval (40% variable density thinning). The two locations were within the Gray Elk Timber Sale within subdivisions 54 and 54a for the covered and thinned, respectively.

The sites share similar topography-and overstory Douglas-fir and Ponderosa pine vegetation in a mixed-conifer forest of the Pacific Northwest. Both sites are located on the middle backslope between 0% to 17% slope and between 5° to 17° northern aspect. The covered site was located at coordinates N 42° 7' 27", W123^o 20' 33" and the thinned site was located at N 42° 7' 29", W123^o 20' 33". Soil moisture and temperature regimes were identical due to the close proximity of both locations between 1,340 m (4,400 ft.) to 1,300 m (4,280 ft.) elevations for the covered and thinned site, respectively. Granitic parent materials were extensive and weathered to the coarse-textured soils found on both sites.
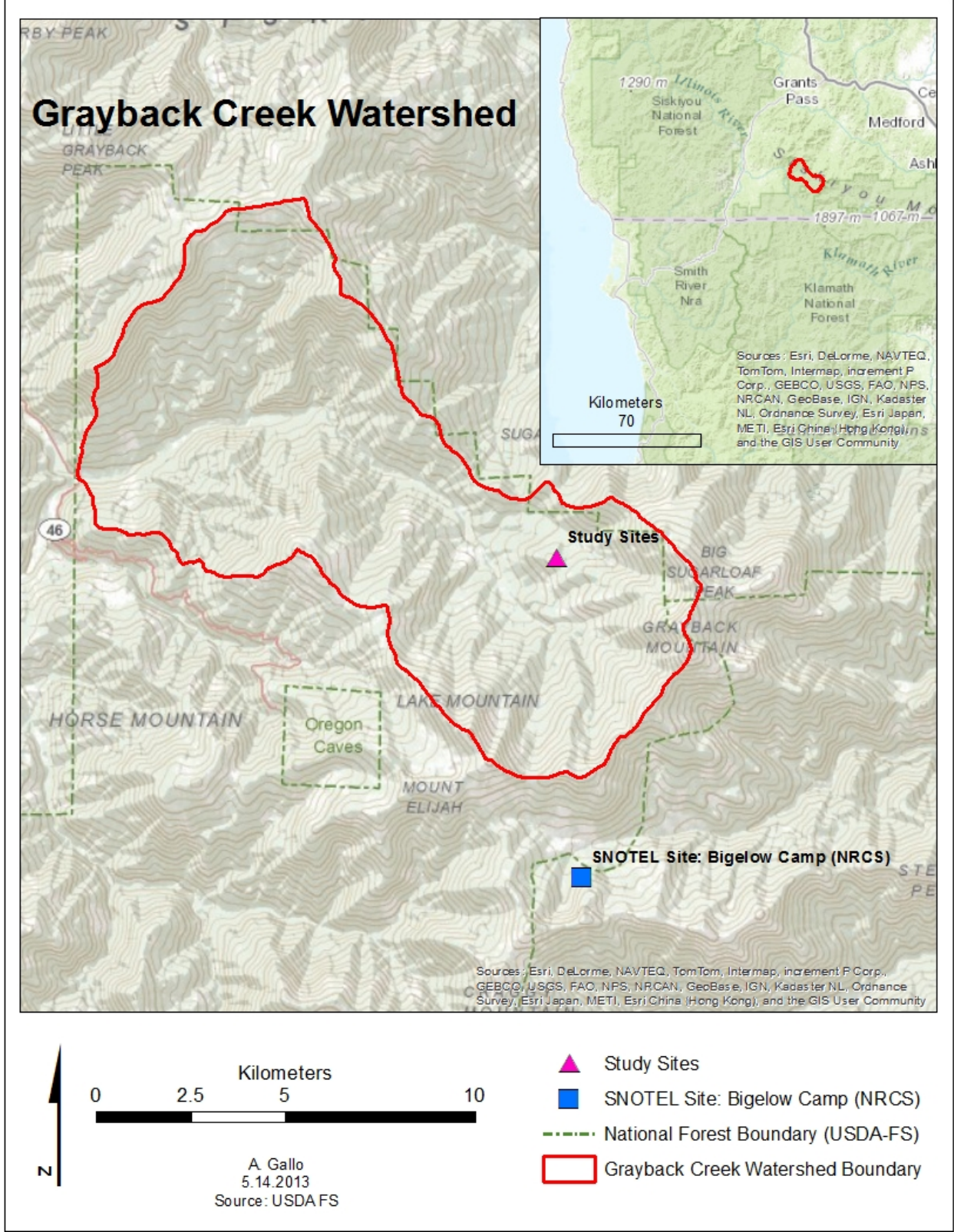
Figure 1. General site location of the Snow Telemetry (SNOTEL) site at Bigelow Camp relative to the study site location in the Grayback Creek watershed, southwest Oregon.

The two forest management techniques of both sites yielded different canopy and understory expressions. Canopy closure data was collected on November 5, 2012 by J.D. Brazier. Average canopy closure on the covered site was 76%, while average canopy closure on the thinned site was 51%. The covered stand contained grass species that provided 100% effective soil cover with areas of madrone seedlings. The understory vegetation on the thinned was isolated pockets of grasses, snowberry, blackberry, whipple vine, and Oregon grape that provided approximately 40% effective soil coverage.

Material collection

Soil samples were collected on August 28, 2012 from three representative pedons for the covered site and four representative pedons for the thinned site. The sample bags were separated from representative pedons, but were treated as identical samples of each horizon (set *A* and set *B* for each horizon)(Appendix- Part II).

Soil moisture and temperature devices

Soil volumetric water content (VWC) and soil temperature were recorded hourly at 5, 15, and 30 cm depths with Decagon GS-3 probes and Decagon EM-50 data loggers. The accuracy range of the Decagon GS-3 probes is $\pm$ 3% VWC and $\pm$ 1°C (Decagon Devices Inc., Pullman, WA). Precipitation and snow water equivalent (SWE) records were recorded from a Natural Resources Conservation Service (NRCS) Bigelow Camp SNOTEL (Snow Telemetry) site. Canopy coverage was measured at each data logger with a densiometer (spherical model C) in all directions (Forestry Suppliers Inc., Bartlesville, OK). All moisture and temperature values were averaged on an hourly basis in addition to calculation of standard deviations.

Treatment of samples

Samples were air dried for five months, August 2012 to February 2013, and then ground using a mortar and pestle and passed through a 2-mm diameter sieve. The percent of total carbon and nitrogen were determined on February 5, 2013 using a carbon and nitrogen combustion analyzer. Each A and B set of horizon samples were duplicated (n=4) and analyzed on a VarioMAX CNS combustion analyzer (Elementar Americas Inc., Mt. Laurel, NJ).

Horizon textures of the thinned and covered sites were analyzed on April 8, 2013 for set *A* and April 15, 2013 for set *B*. Soil textures were quantified by particle size analysis (PSA) on set *A* samples using chemical dispersion by sodium hexametaphosphate (Na-HMP) for samples from both site locations. Set *B* samples were chemically and mechanically dispersed using Na-HMP and an industrial blender, respectively, for samples from both site locations. Both set *A* and set *B* horizon textures were calculated according to the American Society for Testing and Materials (ASTM) using the hydrometer and sieve method (Volk, 1937). The accuracy for both analyses were determined based on the percent relative difference (% RD) of known standards. Using Rosetta® software (V1.2 USDA: Agricultural Research Station – Salinity Laboratory) and data collected from the PSA analysis, Θ_s (saturated water content) was determined for each soil horizon.

Carbon dioxide (CO_2) respiration was analyzed at horizon samples from both sites. A representative 40 g sample was placed into a plastic beaker with perforations and a 0.45 microfiber filter on the bottom. A 25 mL aliquot of deionized water was added to a glass jar containing the plastic beaker and a Solvita low CO_2 pad (Woods End Laboratories, Mt. Vernon, ME). The wetting of air dried samples emulated the rewetting conditions of the first precipitation event of the water year. The glass jars were incubated for 22 hours at three air

temperature treatments of 0, 8, and 20°C to best emulate field soil temperature conditions. The

CO_2 respiration was determined from a digital colorimetric reader (DCR) (Woods End

Laboratories, Mt. Vernon, ME). All samples were analyzed in duplicate with a blank at each

temperature treatment. Readings were taken in replicate to ensure equipment accuracy.

RESULTS AND DISCUSSION

PSA: an unexpected finding

The method difference between the two sets yielded significantly higher sand contents

using set *A*. The use of only chemical dispersion in set *A* likely caused flocculation of particles

(Bouyoucos, 1962). The flocculation of finer particles likely created low clay and silt contents

and artificially high sand contents. The flocculation of finer particles more heavily influenced the

clay textures as evidenced by the % RD range for clay sized particles from 22-60% compared to

39-90% for silt sized particles (Table 1).

Table 1. The horizon textures by particle diameter for both the *A* and *B* set and a % RD between the two set textures.

Horizon (in.)	Clay-*A*†	Silt-*A*†	Sand-*A*†	Clay-*B*‡	Silt-*B*‡	Sand-*B*‡	Clay	Silt	Sand
	------------------------g particles 100g^{-1} soil------------------------						----------% RD§---------		
C 2-6	2	14	84	9	36	55	22	39	153
C 6-14	3	23	74	9	31	60	33	74	123
C 14-23	4	21	75	13	31	56	31	68	134
C 23-44	5	28	67	14	31	55	36	90	122
T 1.5-4.5	4	14	82	11	26	63	36	54	130
T 4.5-10.5	6	19	75	10	28	62	60	68	121
T 10.5-22.5	5	16	79	12	26	62	42	62	127
T 22.5+	4	6	90	7	10	83	57	60	108

† Indicates horizon sample run through method *A*
‡ Indicates horizon sample run through method *B*
§Percent Relative Difference (% RD) equals $\frac{g\ particles\ per\ 100g\ soil\ determined\ by\ a\ set}{g\ particles\ per\ 100g\ soil\ determined\ by\ b\ set}$ x 100%

The method difference between the two sets was based on the hypothesis that physical

dispersion in PSA may not be important for coarse-grained (high sand content) horizon samples.

This hypothesis was incorrect and showed that flocculation effects small amounts of clay sized

particles without using physical dispersion via an industrial blender, as described by Bouyoucus

(1962). We determined the more accurate method for determining the textures of the sandy,

coarse grained samples to be the *B* method. This was based on the relatively uniform range of

clay contents found in the *A* set that ranged from 2-6% compared to a range from 7-14% for the

B set (Table 1). The soil textures of the horizons were fairly uniform since all horizons were

loamy sands except for the sand C horizon on the thinned stand (Table 2).

Table 2. The horizon textures for PSA using method *b* for the covered and thinned sites.

Horizon (in)	Soil texture†
C 2-6	Loamy sand
C 6-14	Loamy sand
C 14-23	Loamy sand
T 23-44	Loamy sand
T 1.5-4.5	Loamy sand
T 4.5-10.5	Loamy sand
T 10.5-22.5	Loamy sand
T 22.5+	Sand

† According to USDA soil textural triangle

Seasonal soil moisture variability

The average Θ_s for our soil profiles occurred at approximately 40% VWC. The driest

period of the year occurred at the same time for both stands, however the thinned stand contained

twice as much water compared to the covered stand at the surface (11% and 5% VWC

respectively) (Fig. 2 and 3). The covered stand rarely reached the Θ_s threshold, ~40% VWC, and

only at areas deeper than 20cm for short periods of time. The events reaching Θ_s on the covered

site were restricted to deeper soil horizons (>30cm). The thinned stand reached the Θ_s threshold

from at least five separate precipitation events. The Θ_s threshold was reached throughout the

entire profile depth. For rain events later in the season, the soil remained saturated up to 3 days.

There is also evidence of VWC fluctuations deeper in the soil (30 cm) as dependent on the time

of day only on the thinned site. These diurnal fluctuations in soil moisture are not as large as

those on soil temperature on a 24-hour timescale.
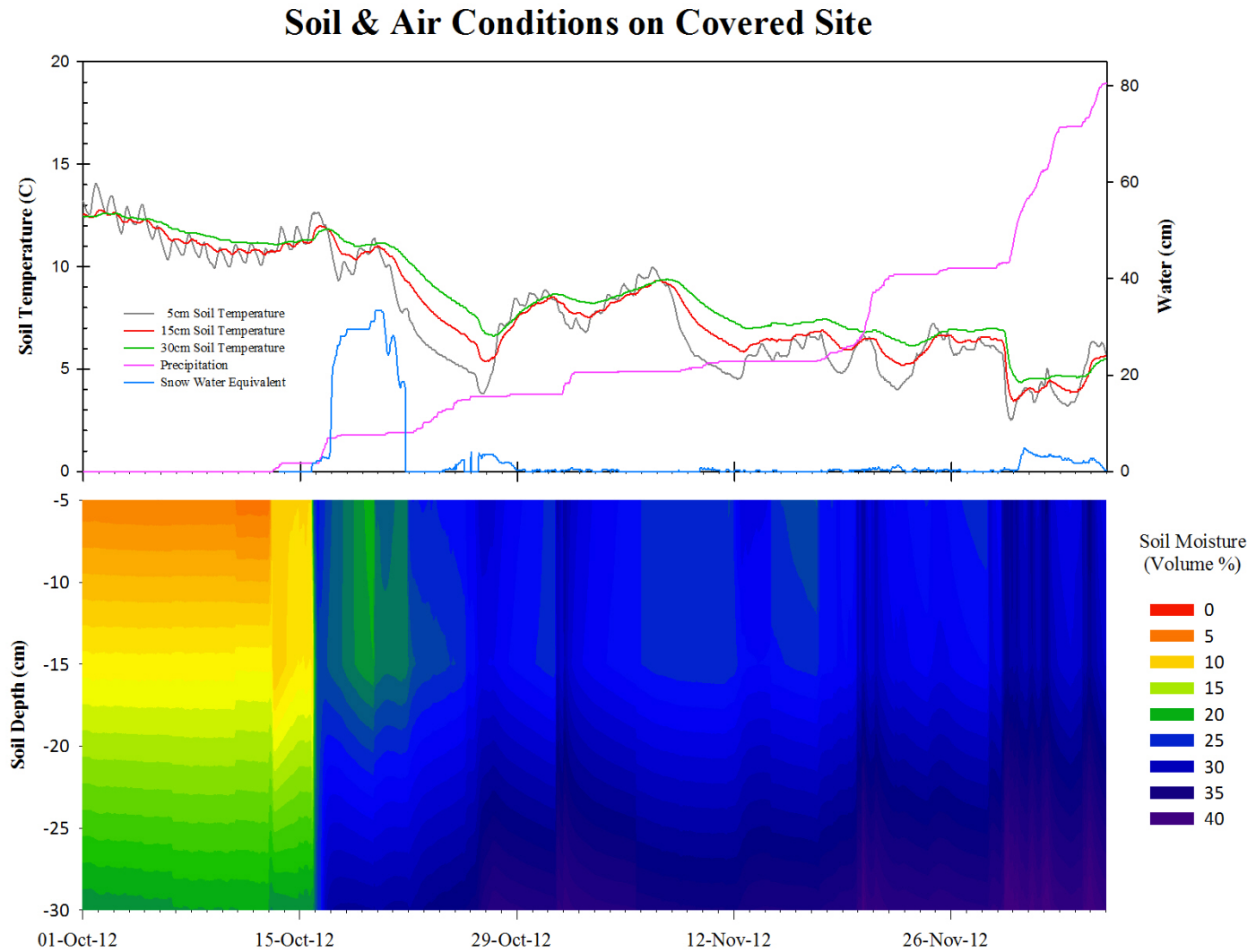
Figure 2. The trends of the covered site for soil moisture and temperature data collected from the Decagon GS-3 probes compared to rain and snow event data collected from the NRCS (Natural Resource Conservation Service) SNOTEL (Snow Telemetry) site at Bigelow Camp, SW Oregon.
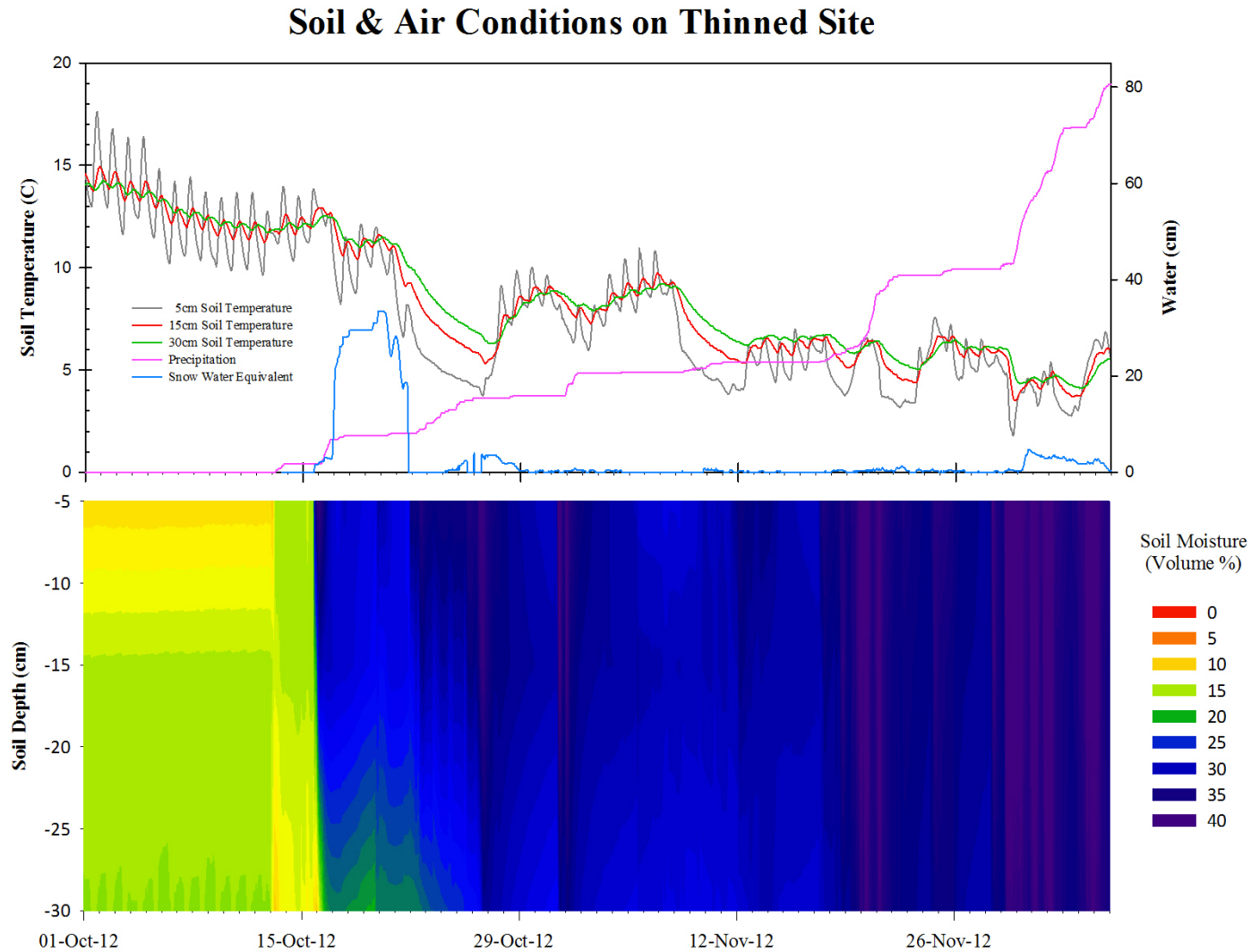
Soil & Air Conditions on Thinned Site

Figure 3. The trends of the thinned site for soil moisture and temperature data collected from the Decagon GS-3 probes compared to rain and snow event data collected from the NRCS(Natural Resource Conservation Service) SNOTEL (Snow Telemetry) site at Bigelow Camp, SW Oregon.

Seasonal soil temperature variability

The magnitude of diurnal flux was greatest at the surface soil horizon (5 cm) for both stands. The covered stand had a maximum flux of approximately ±2.5°C (5 cm) occurring early in the water year from October 1st to the first rain event. The thinned stand had a maximum diurnal flux of ±5°C (5 cm) occurring during the same time frame as the covered stand. As depth of soil increases, the magnitude of flux decreases. The maximum diurnal flux at 30-cm depth on the covered and thinned stands were ±0.2°C and ±0.5°C respectively. The covered site also had slightly lower baseline soil temperatures at 30-cm depth (~11-12°C). Relative to the covered site, the thinned site was slightly warmer (~13-14°C) at the 30-cm depth throughout the driest period of the year. The Θ_s level was reached throughout the entire profile during the first rain event. For some rain events later in the season, the soil remained saturated for approximately three days. Overall the thinned stand contained more VWC with depth and over time through the first season compared to the covered stand.

There was a significant decrease in soil temperatures in both stands following the first snow event that delivered up to 38-cm of SWE to the area. Both stands reached their absolute minimum temperatures of 3.7°C (5 cm) on October 26th following the melt of a second, but smaller, snow event. During the time the soil had snow cover, there was some degree of diurnal flux, however it was smaller compared to the warmer periods of the year. When the snow from the first, and larger, event melted off there were overall decreases in soil temp (between a 4-7°C impact) throughout the profile and very little influence from diurnal flux during the cooling period.

Effects of initial precipitation events on soil moisture and temperature

The first rain event occurred on October 13th, however there was less than 2-cm of rain delivered in the event (Appendix- Part III and IV). The VWC contents increased by approximately 5% at the surface (5 cm) on both stands; however at 30-cm depth the stands reacted differently. The covered soil moisture probe at 30-cm depth recorded an increase of 1% VWC after the first rain event; however the thinned site recorded a 3% decrease in VWC. On October 16th, 3-cm of SWE were delivered immediately before another small (3-cm water) rain event. A subsequent snow event later delivered up to 33-cm SWE, in the form of snowpack. However the soils were the most wet following the initial rain on snow event compared to when snowpack remained on the soil surface. The covered and thinned sites showed a distinct drying trend, 11% and 10% respective VWC decrease, at 5-cm depth immediately following the rain on snow event when snow was covering the soil surface. Data analysis on the covered site suggest the wetting front originated from below (>30 cm) and was a significant factor in wetting the soil. Conversely, the thinned site shows the wetting front always began at the surface and migrated downward through the profile. There is discrete behavior of the soil VWC infiltrating through the soil profile upon reaching the Θ_s threshold on the thinned site.

Discussing the trend differences in soil moisture and temperature of the two stands

The covered stand had significantly denser understory vegetation throughout the site. Therefore the evapotranspiration demand in the shallow (0-30 cm) soil should also be greater than the thinned site. The data during the driest period of the year supports this hypothesis because there was twice as much water at 5-cm depth in the area with less understory vegetation. This implies the water losses due to evaporation are less than the losses due to transpiration of plants and other organisms at the surface. However, we also notice that the overall thinned soil

profile is consistently 1-2°C warmer at all depths than the covered site throughout this study. The lack of understory vegetation on the thinned site allows for more solar radiation to make contact with the soil surface. The soil surface on the thinned site is also more exposed to cooler temperatures at night leading to a greater magnitude of temperature flux. The diurnal flux on the thinned site at the soil surface was 5°C, but only 2.5°C on the covered site due to the insulation of air and interception of sunlight afforded by the dense grass species.

The difference in understory vegetation also led to significant differences in how the water was utilized once water infiltrated the soil. The covered site rarely reached the Θ_s threshold due to high demand for water in the upper soil (0-15 cm). The quantity and size of roots in the covered profiles were very high compared to the thinned stand soil pits. The thinned site also maintained the Θ_s for an additional three days later into November and December. The most intense rainfall period of this study delivered ~40-cm of water within six days. This period helped to saturate the soil on the thinned site and may have allowed a significant amount of water to move into deeper soil horizons and possibly into groundwater. The covered site exhibited a high demand for water in the upper horizons. However, there seems to be an upwelling effect of soil moisture possibly caused by ponding in deeper horizons or ground water flow from the above hillslope.

Using depth to predict the trend in CO_2 respiration

An incubation temperature of 0 ±2°C showed the average CO_2 readings (n=4) decreased in samples from the covered stand. The duplicate samples (n=2) and replicate readings (n=2) were combined to give the average CO_2 reading. The correlation coefficient (R^2) was 0.85 for the covered stand at the 0°C incubation temperature and surpassed the target value of 0.80. The CO_2 readings from the thinned site were too low for the DCR to determine and are excluded from the data set (Fig. 4).

An incubation temperature of 8 ±2°C showed the average CO_2 ppm readings (n=4) decreased in samples from both sites. The correlation coefficient was significantly higher in the covered samples of 0.91 compared to thinned samples of 0.52 using depth to predict CO_2 respiration (Fig. 5). The thinned sample R^2 did not meet the target value of 0.80 for the correlation coefficient, while the covered sample set met the target R^2 value.

An incubation temperature of 20 ±2°C showed the average CO_2 ppm readings (n=4) decreased in samples from both sites. The correlation coefficients were 0.84 and 0.88 for the thinned and covered stands, respectively (Fig. 6). Both sample sets met the target 0.80 correlation coefficient.

The respiration of CO_2 decreased with increasing depth within the soil profile at all incubation temperatures. The average CO_2 respiration did increase in the Cr horizon of the thinned site, which also contributed to the low R^2 value at the 8°C incubation temperature for the thinned site (Fig. 5). The high correlation coefficients to predict CO_2 respiration using depth as a predictor variable indicated the CO_2 respiration for each horizon was dependent on the sample depth.

However, samples were taken from a depth range and may not accurately represent specific depth values. Attempts to explain the trend of CO_2 at depth by other researchers have been limited, except for an unpublished study that looked at CO_2 trends at varying depths between a north and south aspect (S. Pensky, unpubl. data). A study by Winkler et al. (1996) also looked at CO_2 respiration trends at varying horizons and suggested differences in respiration rates with depth were caused by horizon differences in soil organic matter concentrations. Therefore, examination of substrate quantity, as indicated by total C and N percentages, may better predict the CO_2 respiration rates.
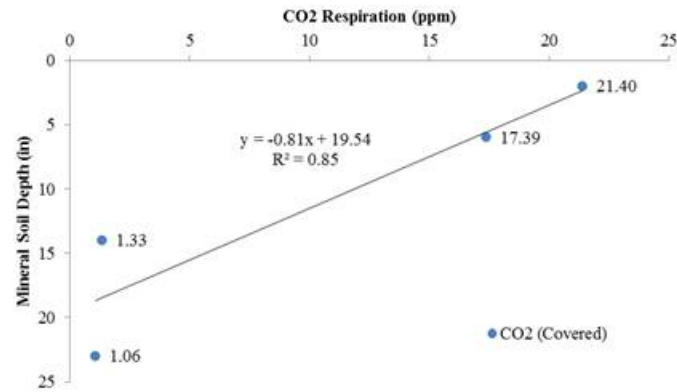
Figure 4. The trend of average CO_2 (n=4) at 0°C incubation with increasing horizon depth compared between the covered and thinned sites.
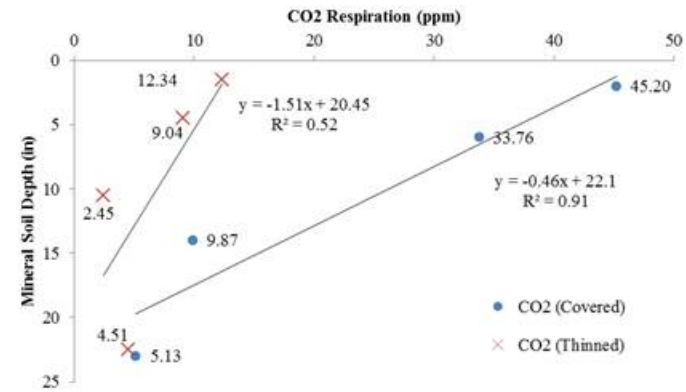
Figure 5. The trend of average CO_2 (n=4) at 8°C incubation with increasing horizon depth compared between the covered and thinned sites.
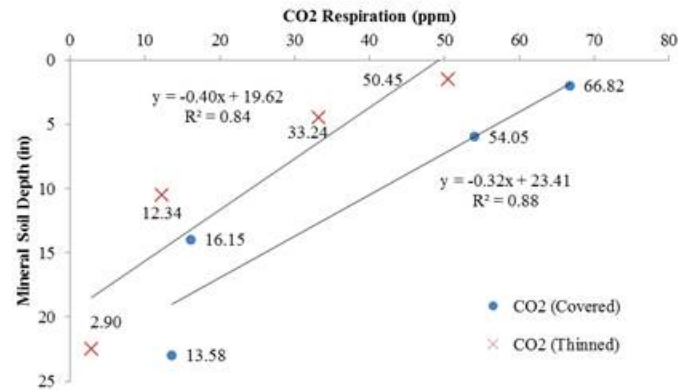
Figure 6. The trend of average CO_2 (n=4) at 20°C incubation with increasing horizon depth compared between the covered and thinned sites.

Dependence of CO_2 respiration on total C and N

The similar trends between CO_2 respiration and the total C and N rates were observed (Fig. 7 and 8). The CO_2 respiration yielded higher values for the covered stand compared to the thinned stand at horizon equivalent depths for each incubation temperature. Similarly, a v-shaped pattern between the two trend lines of the stands for CO_2 respiration with depth was evident for all incubation temperatures. The v-shaped pattern of the trend lines for total C and total N suggested that CO_2 respiration was dependent on the quantity of total C and N in the soil.

The proportion of C and N in the SOM also greatly affects microbial CO_2 respiration (Schlesinger and Andrews, 2000; Paul and Clark, 1996; Persson et al., 1999). Nadelhoffer and others (1990) determined after C:N ratio of soil organic matter ranged from 12 to 15. The C:N ratios of the samples typically ranged from about 20 to 28 (Appendix- Part IV). Therefore, the total C and N in the soil were assumed to be from SOM, and thus SOM and total C and total N will be used interchangeably.

The effective soil cover (ESC) was 100% on the covered site compared to an ESC of 40% on the thinned. The greater presence of understory vegetation on the covered site provided greater SOM, as evidenced by the greater total C and N percentages found in the covered compared to the thinned. The greater quantity of substrate likely provided a greater energy source to support a larger amount of soil microorganisms. The greater energy source was reflected by the greater respiration of CO_2 that represented microbial biomass (Haney et al., 2008).
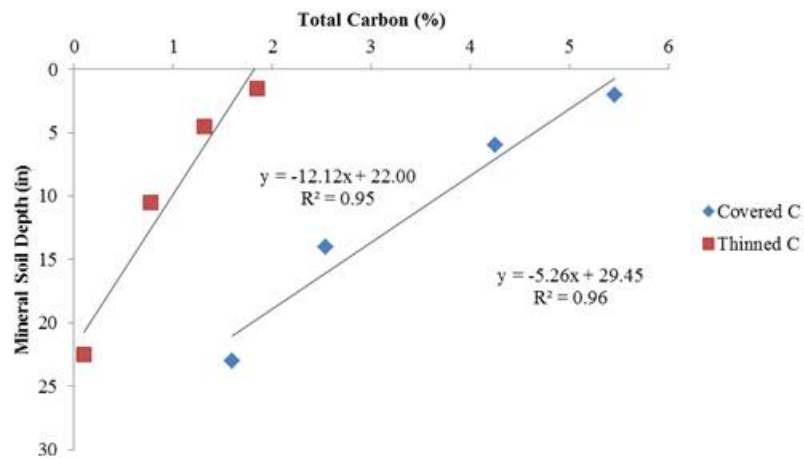
Figure 7. The trend of total carbon percentage with increasing horizon depth compared between the covered and thinned sites.
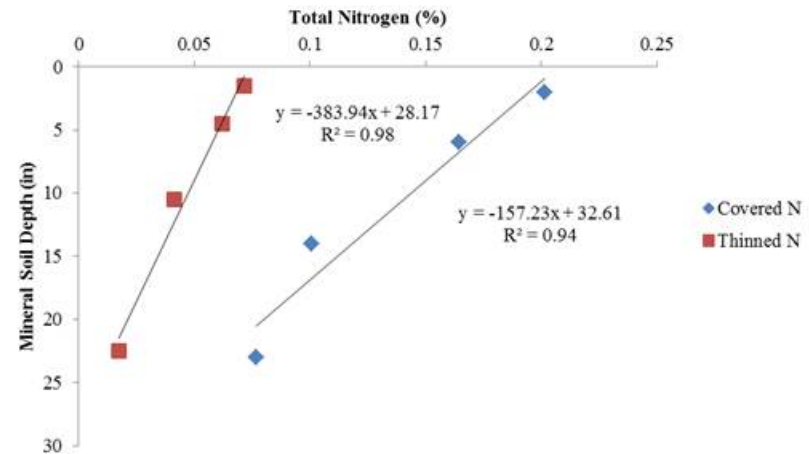
Figure 8. The trend of total nitrogen percentage with increasing horizon depth compared between the covered and thinned sites.

Effect of air temperature incubation on CO_2 respiration

The trend in CO_2 respiration was similar for the thinned and covered sites at each incubation temperature, yet the covered had greater respiration rates compared to the thinned. Generally, the trend in CO_2 respiration was an increase at each horizon (Fig. 9, 10, and 11). The increasing CO_2 respiration with increasing incubation temperatures is a trend is supported by many other researchers (Lloyd and Taylor, 1994; Persson et al., 1999; Pietikainen et al., 2005; Singh and Gupta, 1977; Townsend et al., 1997; Uchida et al., 2010). The surprising trend was the difference between the two stands among the horizons.

The upper two horizons of the covered site had more CO_2 respiration at each incubation temperature relative to the thinned site. The covered stand upper B horizon showed greater respiration rates relative to the A horizon in the thinned stand (Fig. 10). This finding suggested the covered stand had greater microbial biomass in its upper B horizon than the thinned stand had in its A horizon. The trend continued in the lower horizons, whereby the CO_2 respiration in the C horizon of the covered stand was greater than the respiration in the upper B of the thinned site. The C horizon of the thinned was the only horizon that showed an increase in CO_2 respiration with increasing depth (Fig. 11).

The similar trends in CO_2 respiration were consistent with all incubation temperatures. However, slight differences between the CO_2 respiration rate trends suggested an increased dependence on SOM quantity with higher incubation temperatures. The CO_2 respiration differences were greatest in the upper three equivalent horizons at the $8^{o}C$ incubation temperature with a % RD range from 266 to 303% and just 14% in the bottom most horizon equivalent. The % RD of the upper three equivalent horizons ranged from about 32 to 63% at the $20^{o}C$ incubation temperature (Appendix- Part VI).

The broadening of the aforementioned v-shaped pattern suggested a greater correlation to SOM for the thinned stand. The greater dependence of thinned stand CO_2 respiration was evident by the higher R^2 value using total C and N as the predictor variables to explain the trend in respiration (Appendix- Part VII). The increased predictability of respiration based on SOM with higher temperatures suggested that SOM quantity became more important on the thinned stand with increasing temperatures.
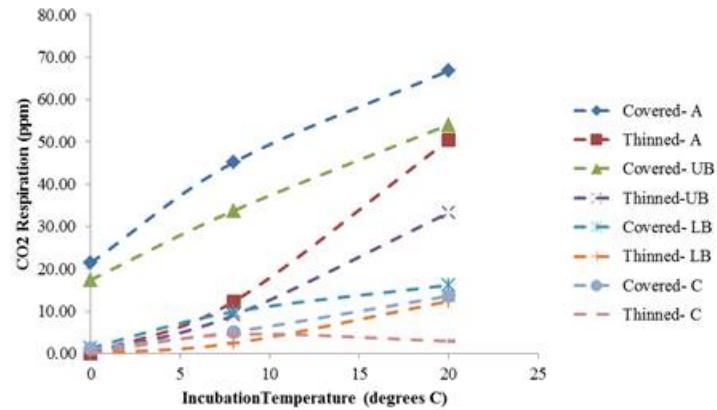
Figure 9. The CO_2 respiration values at the 3 different incubation temperatures for each horizon on the covered and thinned stands.
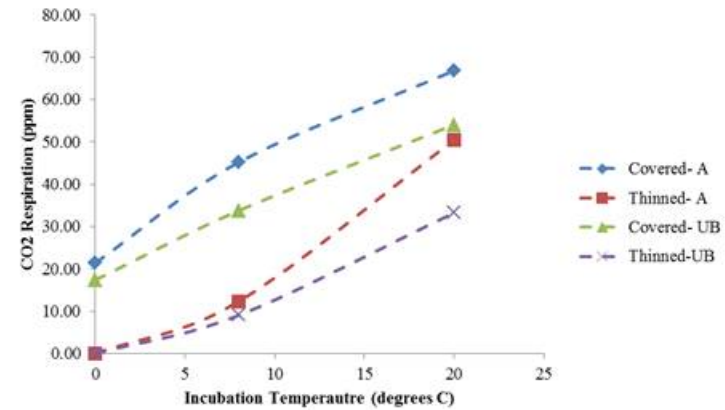
Figure 10. The CO_2 respiration values at the 3 different incubation temperatures for the A horizon (A) and upper B horizon (UB) for the covered and thinned stands.
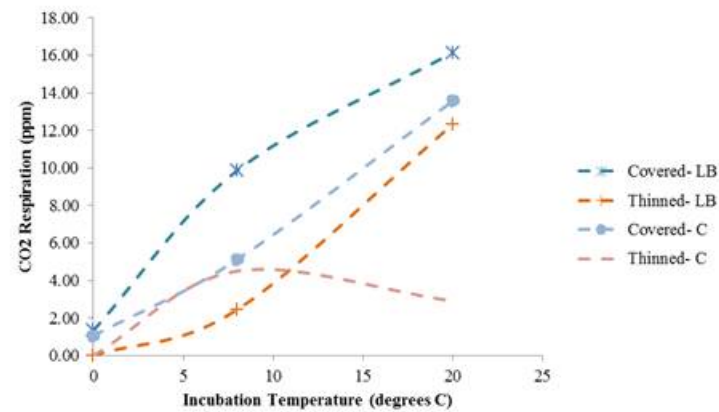
Figure 11. The CO_2 respiration values at the 3 different incubation temperatures for the lower B horizon (LB) and C horizon (C) for the covered and thinned stands.

CONCLUSION

The goal of this study was to examine the differences in soil climate and microbial activity on seasonal timescales as influenced by variable thinning practices on two managed stands. The soil's response to the first rain event, behavior of soil upon reaching saturation, and the magnitude of diurnal flux between the stands were evaluated. The influence of soil temperature, SOM quantity, and trends in soil CO_2 respiration at increasing depth was also be examined.

The significant difference in understory vegetation played a vital role in the moisture and temperature behavior on these study sites. The dense grass species on the covered site had a high demand for water and provided significant cover from the sun on the soil surface. The covered site only reached Θ_s deeper where water may have accumulated over time or from subsurface flow. The thinned site frequently reached Θ_s and may have added a significant quantity of water to deeper soil horizons or possibly acted to recharge groundwater. The lack of vegetation on the thinned site caused the diurnal flux to be significantly greater than the covered site near the soil surface ($\pm5°C$ and $\pm2.5°C$ respectively). The cover of snow decreased diurnal flux; however, the influence of snow melt caused soil temperatures to drop throughout the whole profile (between 4-7°C) and diminished evidence of diurnal flux. Overall the thinned site had higher temperatures, larger magnitude of flux, and higher VWC at all horizons throughout the timing period, suggesting a potentially favorable climate for soil microfauna.

The proliferation of soil microbes was dependent largely upon the depth, and thus distribution of total C and N throughout the soil pedon. The low number of replicates did not allow for quantification of differences between the covered and thinned stand. However, the trends of the covered and thinned stand showed decreasing CO_2 respiration with increasing depth

at almost every incubation temperature. The rate of CO_2 respiration on the thinned site was more dependent on SOM with higher incubation temperatures, as evidenced by the greater R^2 values using total C and N to predict CO_2 respiration (Appendix- Part VI).

The study determined significant impacts of management from 40% variable thinning on southwest Oregon timber stands, as evidenced by differences in response to soil moisture, soil temperature, and SOM quantity for CO_2 respiration. In order to avoid the "black box" notion for microbial processes and species, further research on microbial CO_2 respiration should focus on the in situ species of the samples and deep water transport. Limited funding and research time prevented this study from examining those features. In order to provide a more holistic understanding of forest sustainability, long-term monitoring needs to continue on these timber stands.

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APPENDIX

*Part I.* Soils map of the Grayback Creek watershed area
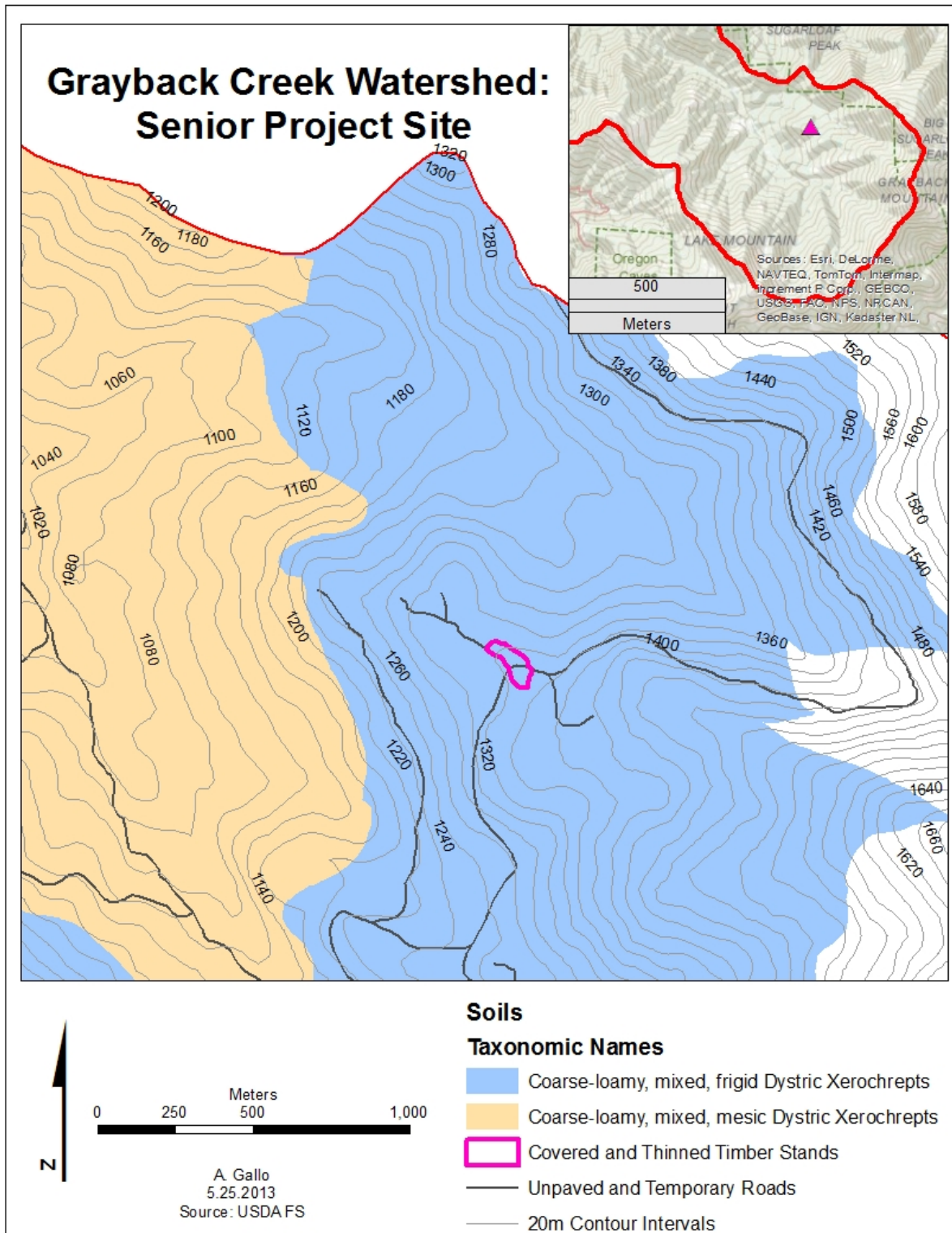
Part II. Pedon description sheets† for the covered and thinned stands.

Horizon (in.)	Horizon	Boundary	Structure	Rock Fragment (%)	Roots
C 0-2	Oi	-	-	-	-
C 2-6	A	AS	3, f, GR	10% sr, gr (1 cm)	m, vf-f; c, md
C 6-14	Bw	CW	2, m, SBK	10%, sr, gr (1-2 cm)	c, f-vf; m, co; f, vc
C 14-23	Bt	DW	2, m-co, GR	10%, sr, gr (<1 cm)	c-m, f
C 23+	CB	CS	0, MA	-	-
T 0-1.5	Oi	-	-	-	-
T 1.5-4.5	A	AS	2, co, GR	sr-ang, gr (3-3.5 cm)	m, vf; c, f; f, md
T 4.5-10.5	Bw1	CS	2, f, SBK	37% sr-r, gr	f, f
T 10.5-22.5	Bw2	GS	1, f, SBK	-	f, co
T 22.5+	BC	CS	0, MA	-	Vf, f

† Abbreviations according to NRCS *Field book for describing and sampling soils, Version 3.0*

Part III. Soil moisture and air data for the first precipitation event on the covered stand
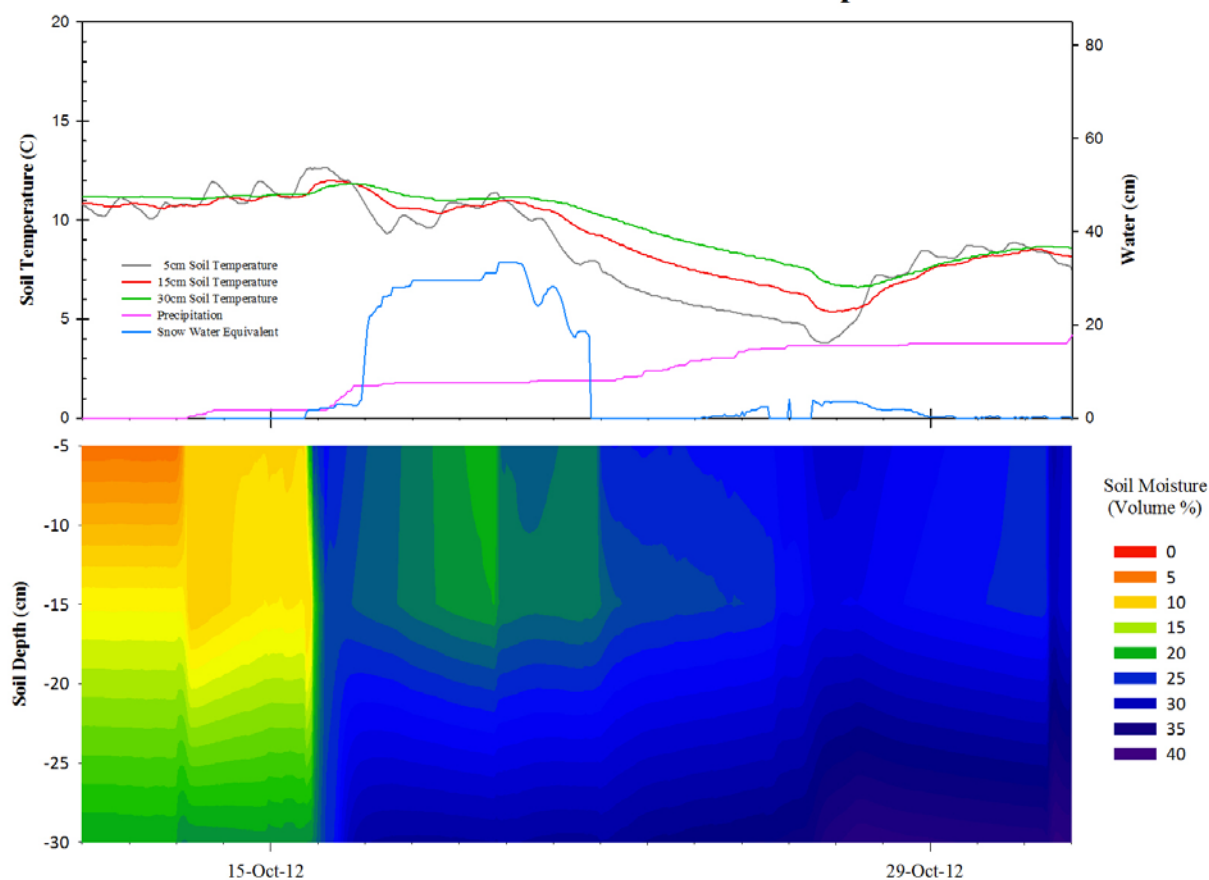
Part IV. Soil moisture and air data for the first precipitation event on the thinned stand
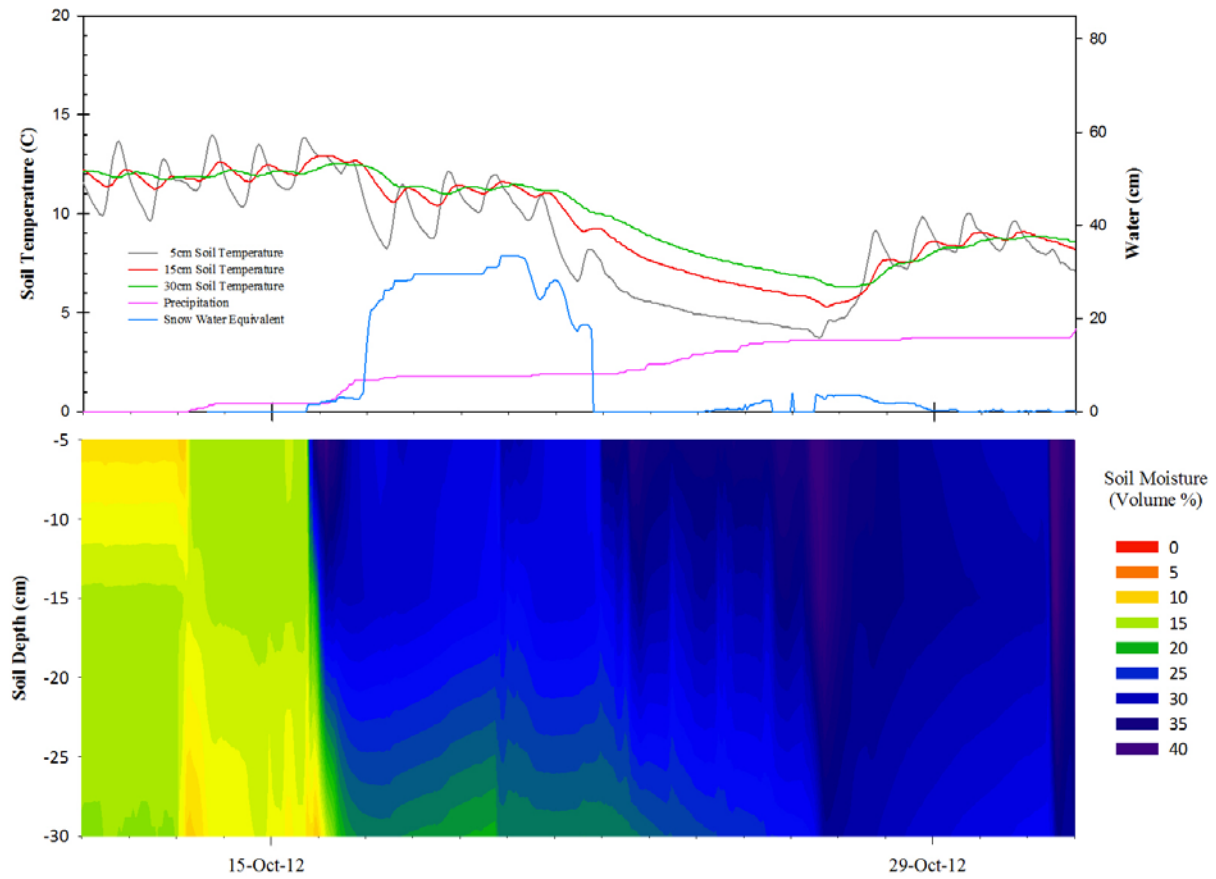
Part V. The trend of average Carbon to Nitrogen Ratio (C:N) with increasing horizon depth compared between the covered and thinned sites

Carbon to Nitrogen Ratio

Plot labels:
- y = -1.09x + 29.12, R² = 0.97
- 25.85
- 27.20
- 20.63
- 25.51
- 18.87
- 25.10
- y = -3.20x + 90.13, R² = 0.90
- 6.04
- 20.74
- ◆ C:N (Covered)
- ■ C:N (Thinned)

Y-axis: Mineral Soil Depth (in)
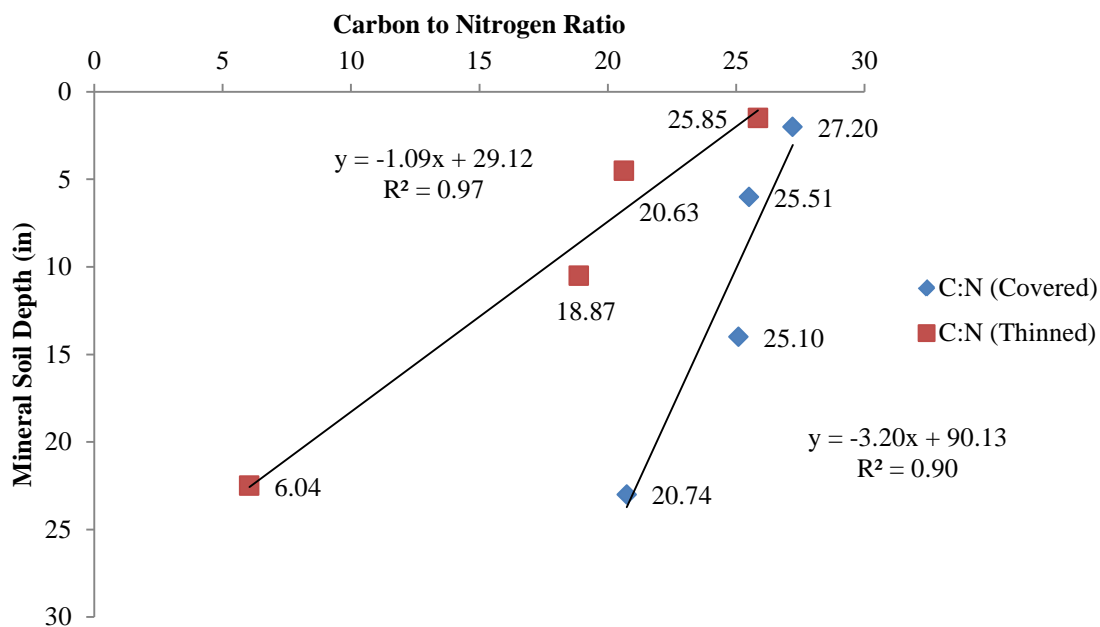
Part VI. The % RD between the covered and thinned stands for their respective incubation temperatures

Horizon Equivalent	0°C	8°C	20°C
	--%RD[†]--		
A	n/a	266	32
Upper B	n/a	273	63
Lower B	n/a	303	31
C	n/a	14	367

† Percent Relative Difference (% RD) equals $\frac{(covered\ CO_2\ respiration - thinned\ CO_2\ respiration)}{thinned\ CO_2\ respiration}$ x 100%
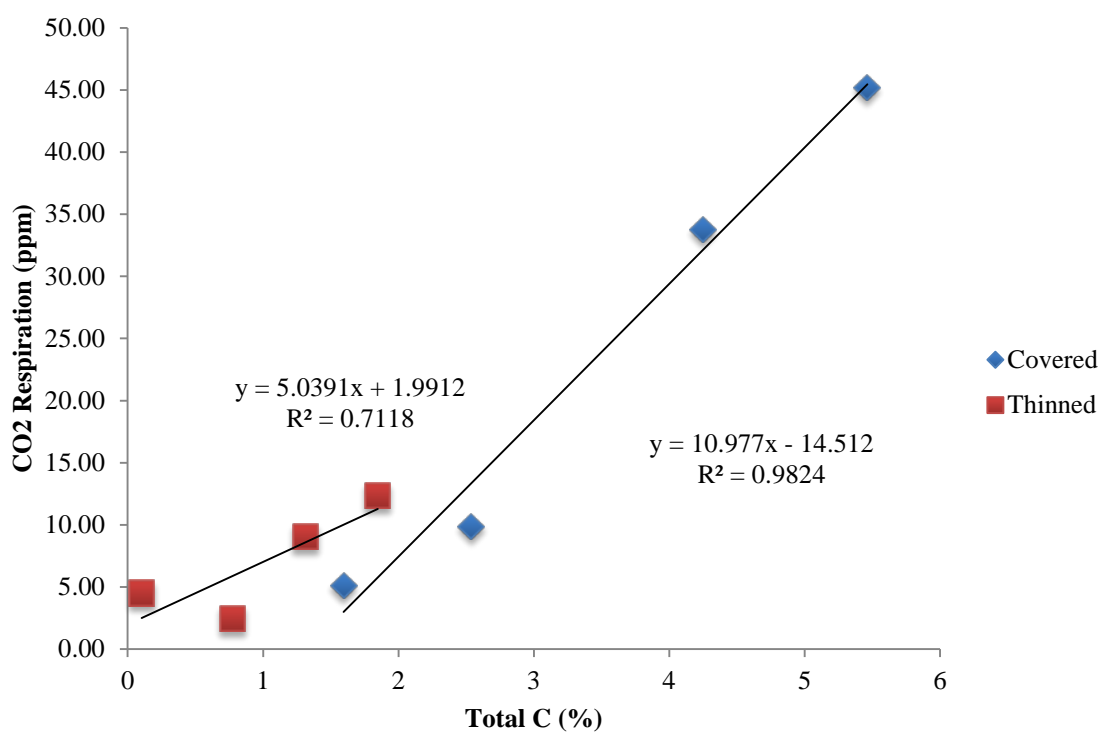
Part VII. Using total C and N to predict CO_2 respiration at the 3 incubation temperatures
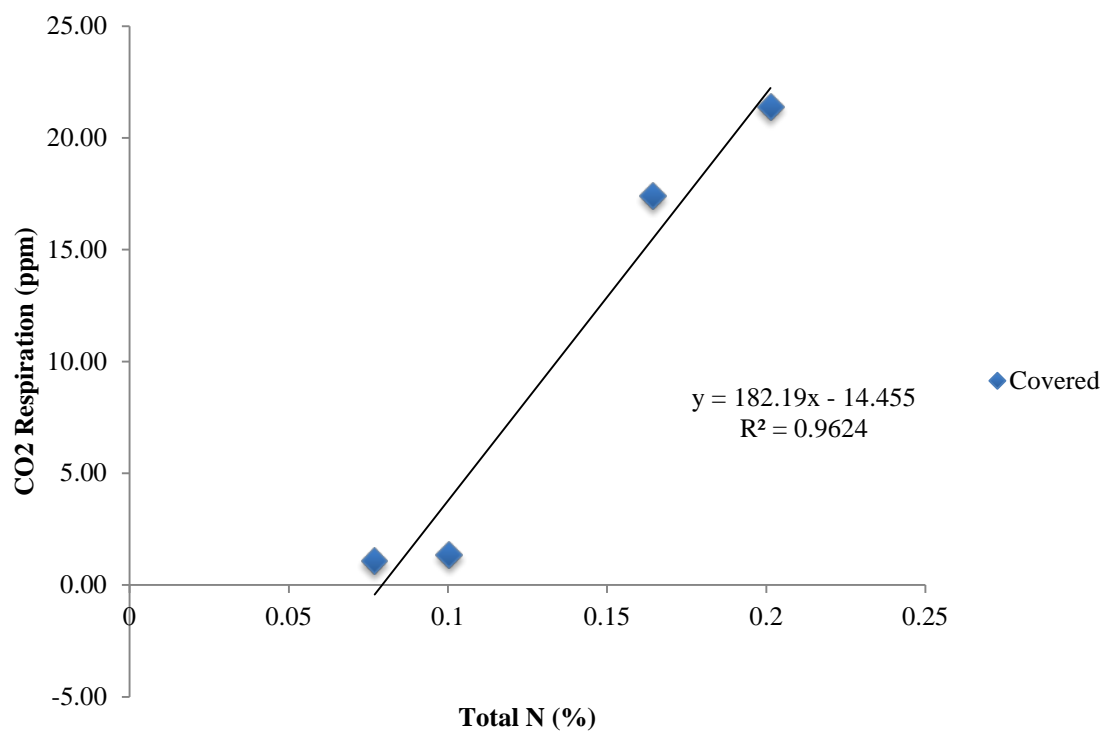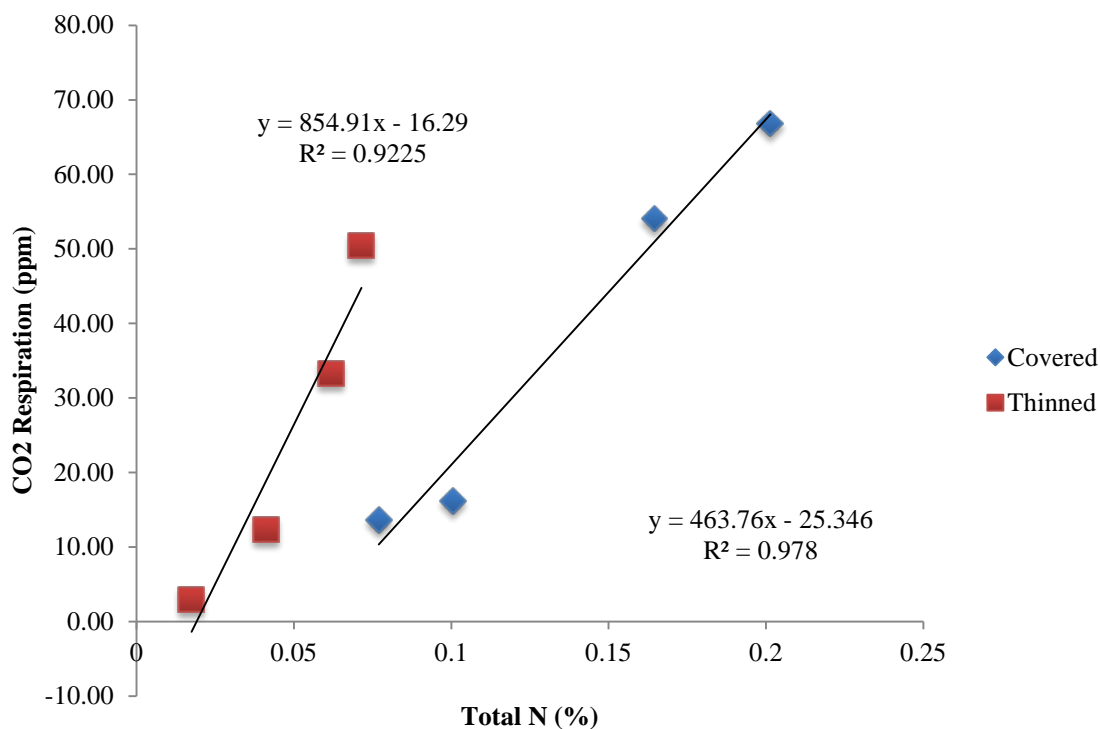

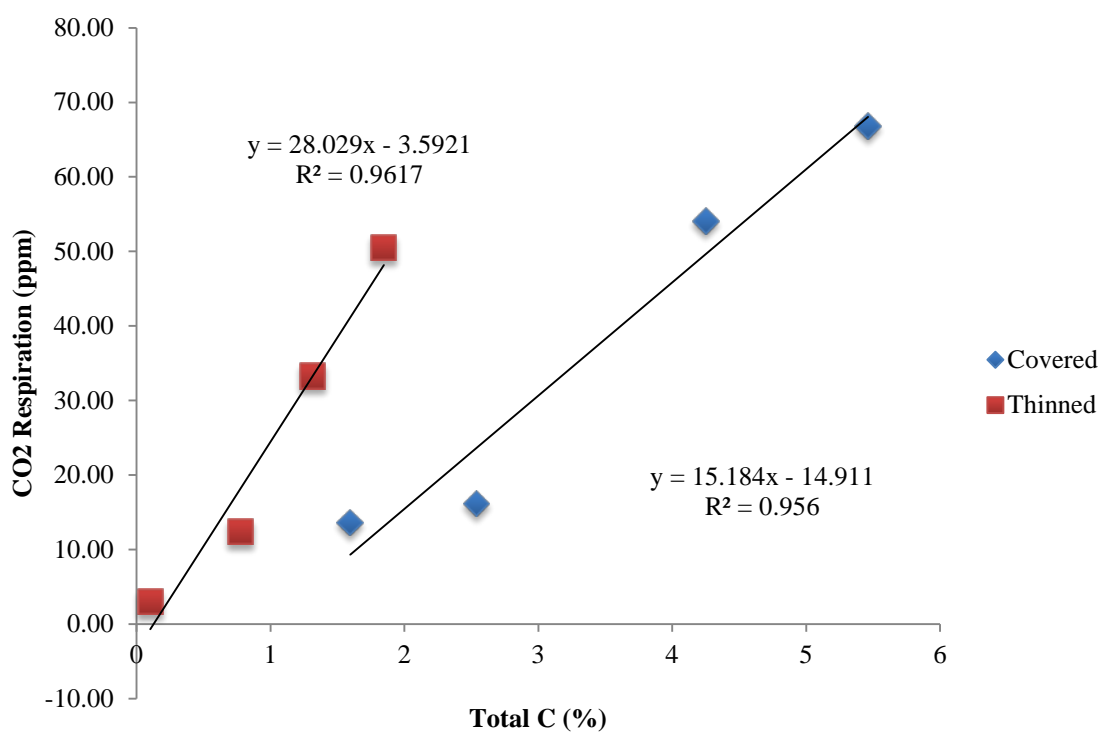Figure 12. Using total N to predict CO_2 respiration at the $0^{\circ}C$ incubation temperature.
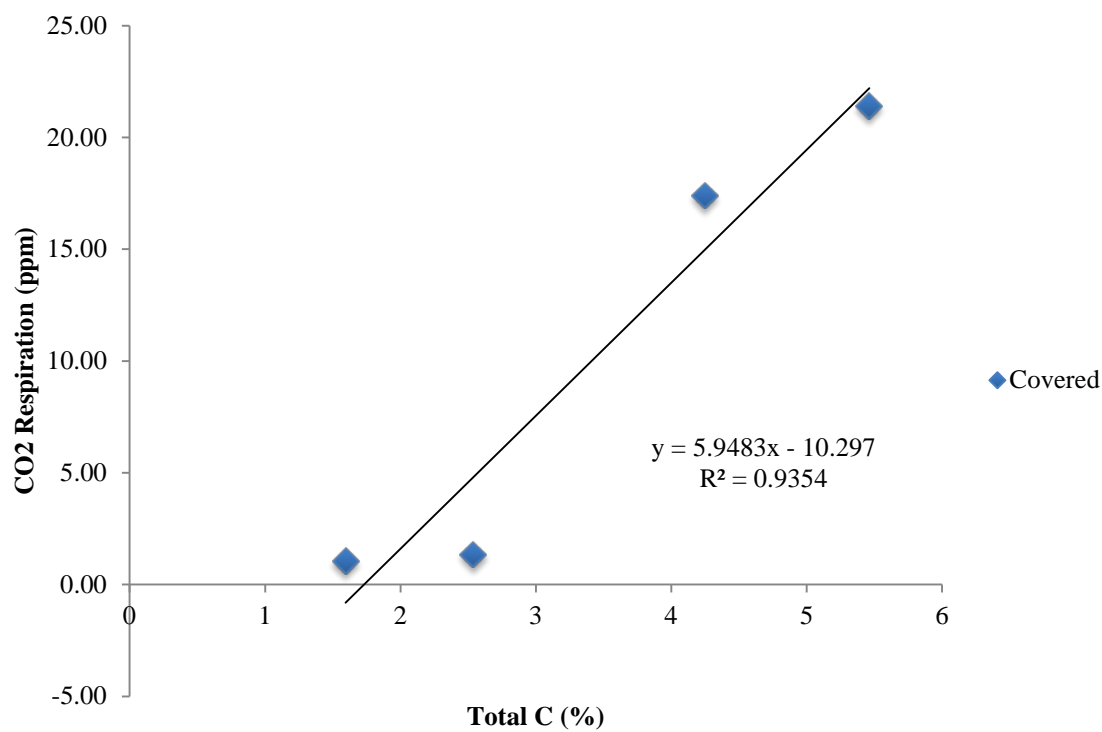
Figure 13. Using total C to predict CO_2 respiration at the $0^{\circ}C$ incubation temperature.
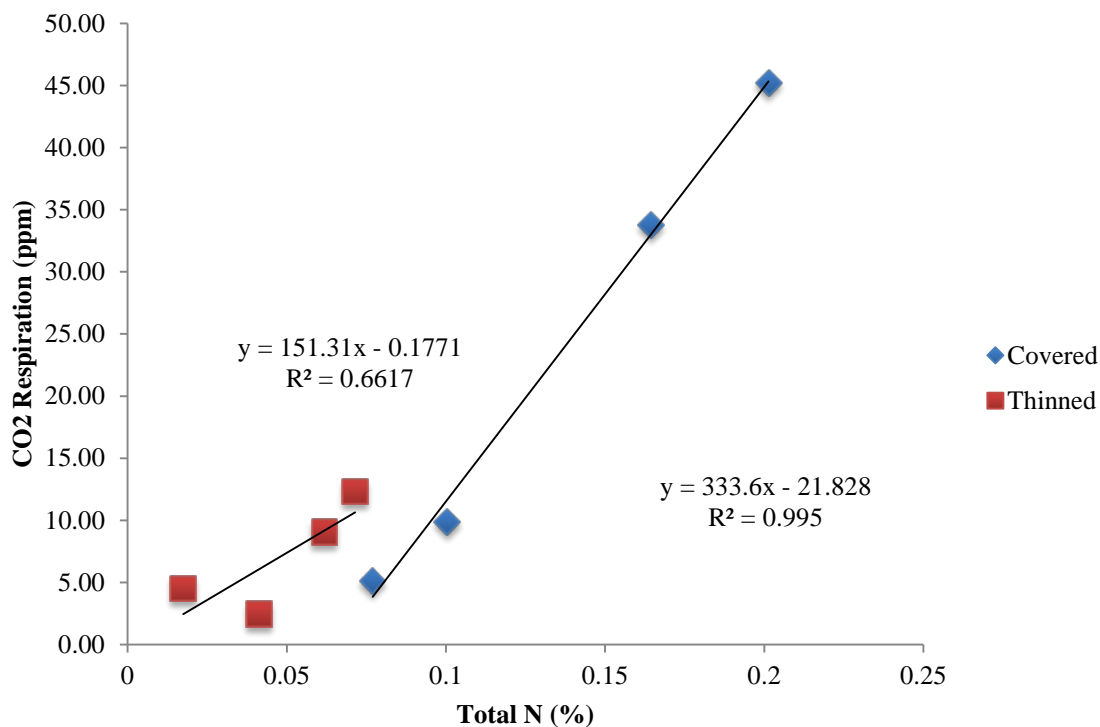
Figure 14. Using total N to predict CO_2 respiration at the 8^oC incubation temperature.

Figure 15. Using total C to predict CO_2 respiration at the 8^oC incubation temperature.

Figure 16. Using total N to predict CO_2 respiration at the $20^{\circ}C$ incubation temperature.

Figure 17. Using total C to predict CO_2 respiration at the $20^{\circ}C$ incubation temperature.

Part VIII. Statistical analyses figures with averages and standard deviations
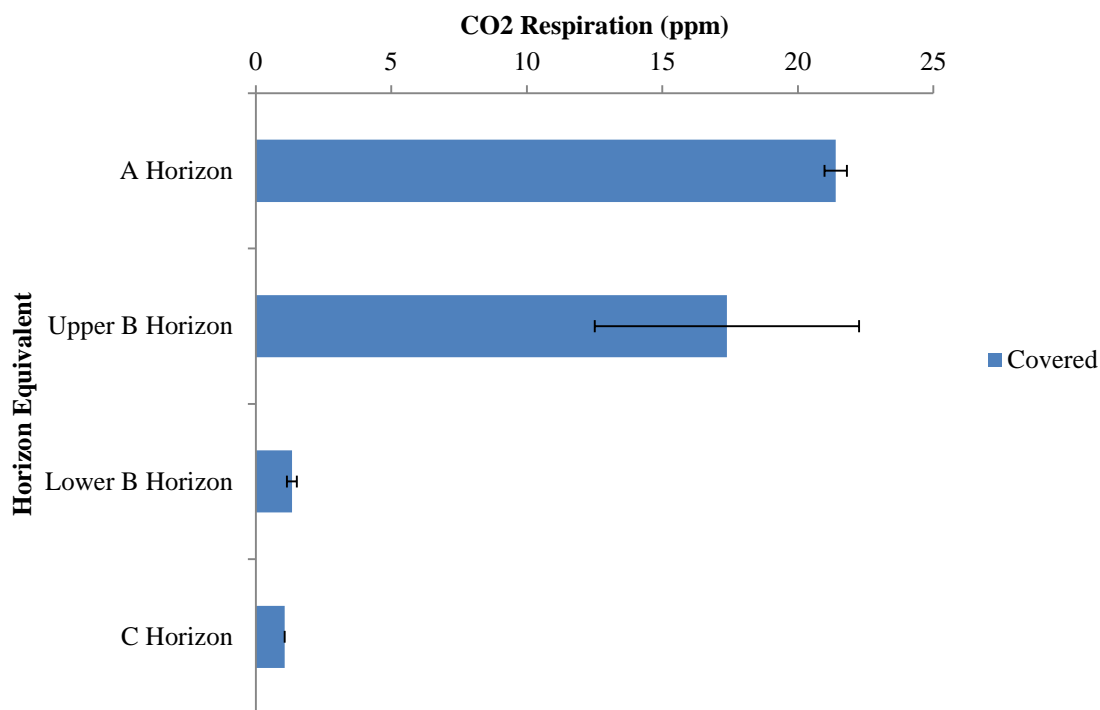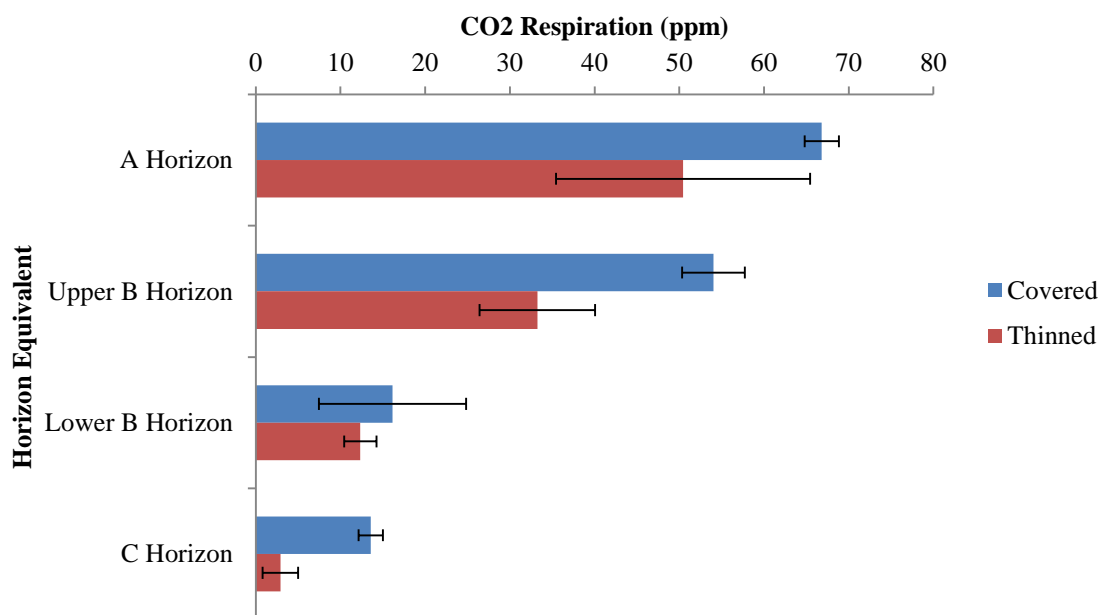

Figure 18. A comparison between the average CO_2 respiration at the $0^{\circ}C$ incubation (with standard deviations) for the horizons of the thinned and covered site.
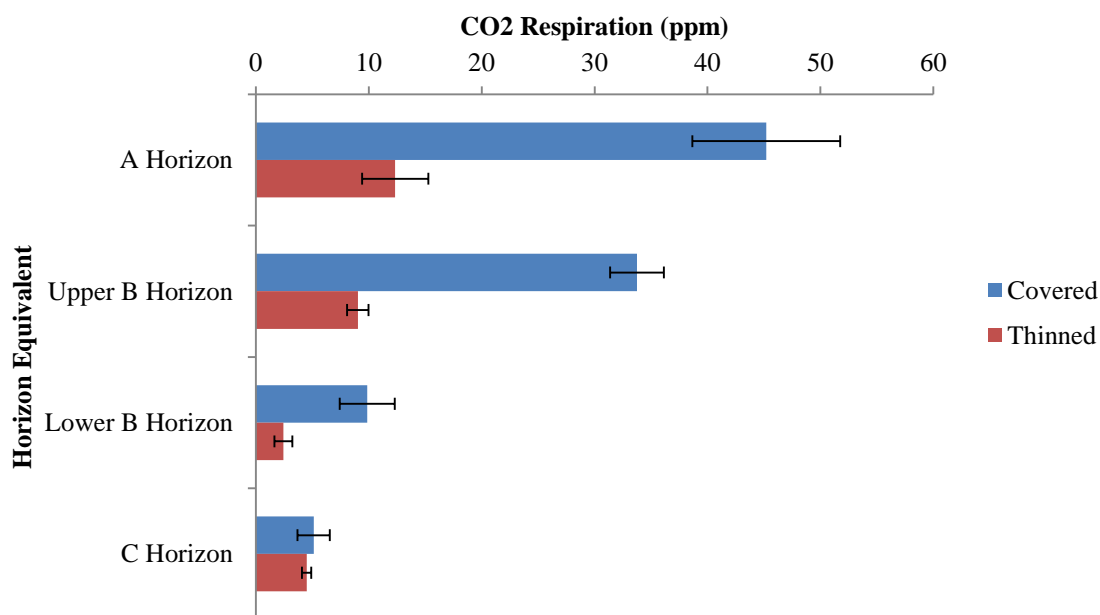
Figure 19. A comparison between the average CO_2 respiration at the $8^{\circ}C$ incubation (with standard deviations) for the horizons of the thinned and covered site.

Figure 20. A comparison between the average CO_2 respiration at the 20^oC incubation (with standard deviations) for the horizons of the thinned and covered site.
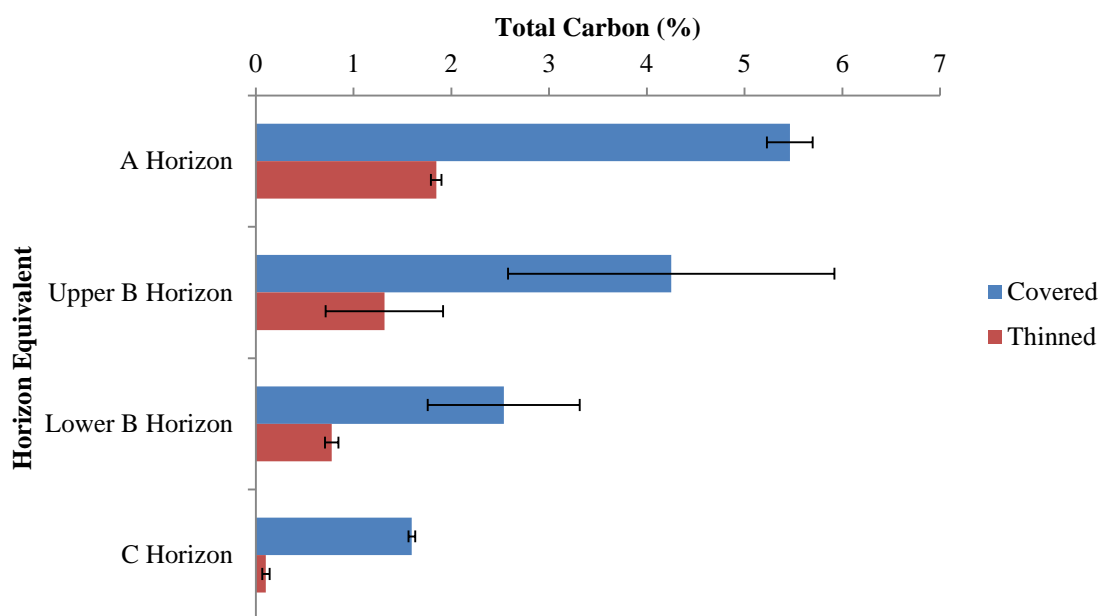

Figure 21. A comparison between the total carbon percentage (with standard deviations) for the horizons of the thinned and covered site.
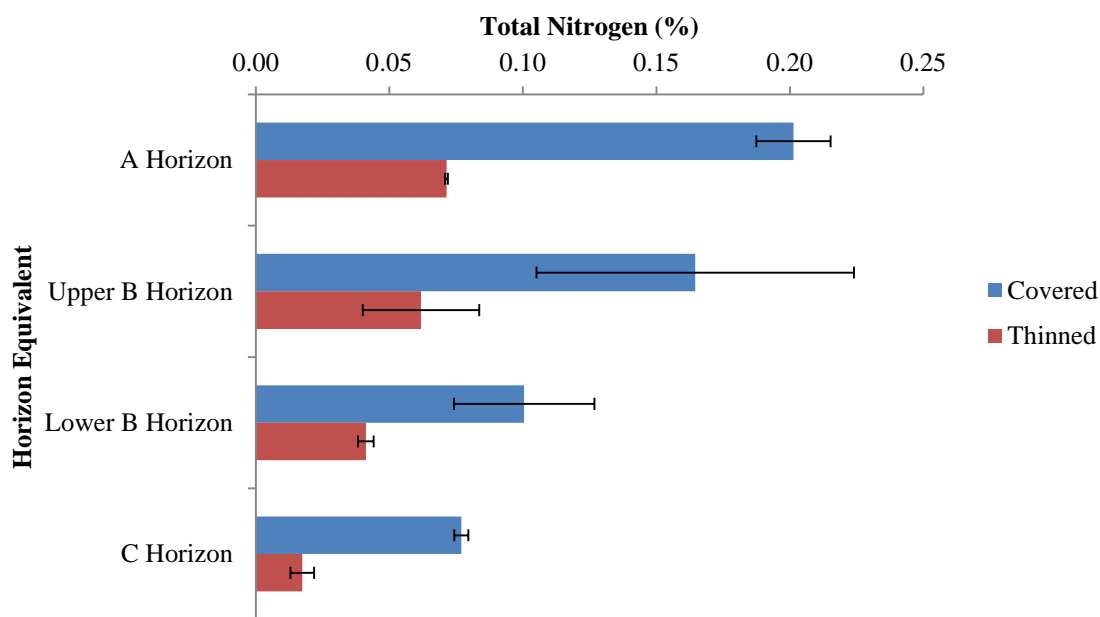
Figure 22. A comparison between the total nitrogen percentage (with standard deviations) for the horizons of the thinned and covered site.
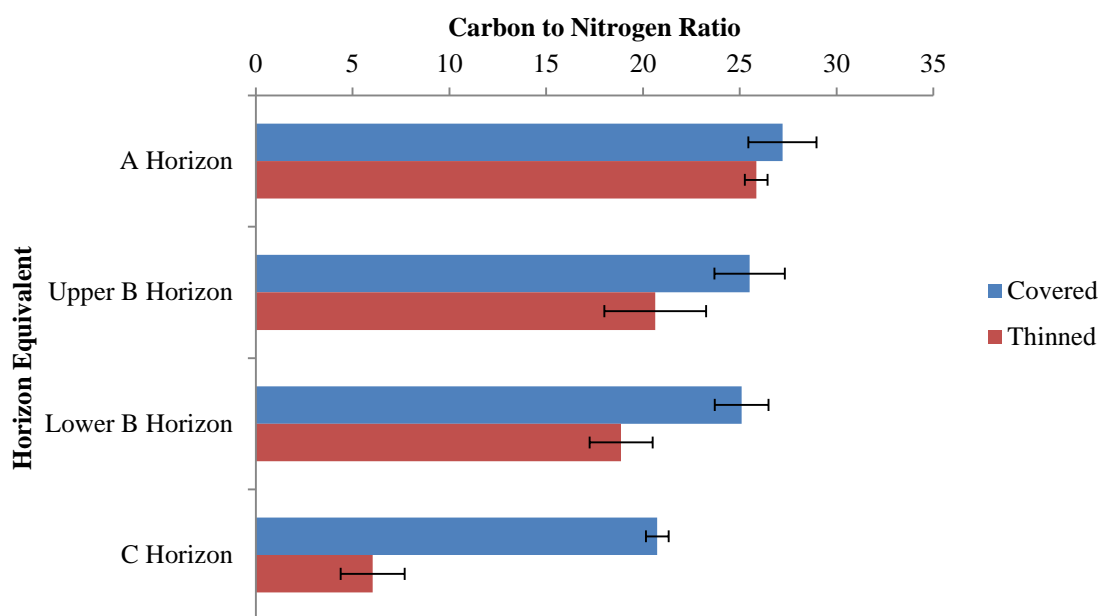

Figure 23. A comparison between the C:N (with standard deviations) for the horizons of the thinned and covered site.

Part IX. Photos of the covered and thinned site, respectively

Figure 24. Photo of the covered stand.

Figure 24. Photo of the thinned stand.