The Effects of Tree Girdling on Soil and Bole Respiration in Big Tooth Aspen Trees (*Populus grandidentata*)

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Abstract

Much attention has been given to the effects of anthropogenic activities on the global carbon cycle. Deforestation and the burning of fossil fuels has added vast amounts of carbon to the atmosphere, while at the same time reducing the number of carbon sinks that are available to sequester the carbon. The focus of this study was to determine the effects of a selected disturbance (tree girdling) on a forest's ability to remain a carbon sink, or transform into a carbon source. A field experiment was conducted on the site of the University of Michigan Biological Station in Pellston, Michigan. Six plots containing Aspen trees were set-up in a block design. All of the trees in the experimental plots were girdled. The soil respiration and bole respiration rates were measured at designated time interval over a period of 26 days. A strong efflux decline trend was observed in the soil of plots where the trees were girdled. However, when a paired t-test was performed only one time interval provide a p value that was significant (p=0.014). Trees that were girdled in March-June of 2007 and July 2006 were included in the bole respiration data. It was found that in all but one of the trees, the area above the girdled area had the highest efflux value; followed by the area below the girdled area and finally the girdled area with the lowest efflux value. It was also found that the trees that were girdled prior to July 2007 had a substantially higher average efflux above the girdled area when compared to the trees that were girdled in July 2007 (9.86 $\mu mol/m^2/sec$ and 4.67 $\mu mol/m^2/sec$, respectively).

Introduction

The Carbon Cycle

The carbon cycle is a substantial part of life as a whole, since a continual supply of carbon is essential for all living organisms. The complete cycle is regulated by "sources" that put carbon back into the environment and "sinks" that absorb and store carbon. The earth contains approximately 10^8 Pg C in: geological formations in the earth's crust; dissolved oceanic carbonates; gas hydrates; fossil fuels; terrestrial biosphere; soils and the atmosphere (Sundquist 1993; Kvenvolden 1993). Natural systems have historically maintained these pools in dynamic equilibrium (Rustad et. al, 2000); however**,** recent human activity has altered the carbon cycle in an adverse manner. The burning of fossil fuels and deforestation has added more than eight billion metric tons of Carbon into the Earth's atmosphere while at the same time reducing the number of sinks that are available to store the Carbon (Appenzcller, 2004). CO_2 is transparent to light, but opaque to heat rays, thus the CO_2 in the atmosphere hinders radiation from leaving Earth, thereby intensifying the Greenhouse effect. Carbon sinks are of paramount importance, because they regulate the amount of CO_2 that enters the atmosphere and contributes to the greenhouse effect (Appenzcller, 2004). By reducing the number of carbon sinks available, the ramifications of increased CO_2 levels in the atmosphere will affect generations to come.

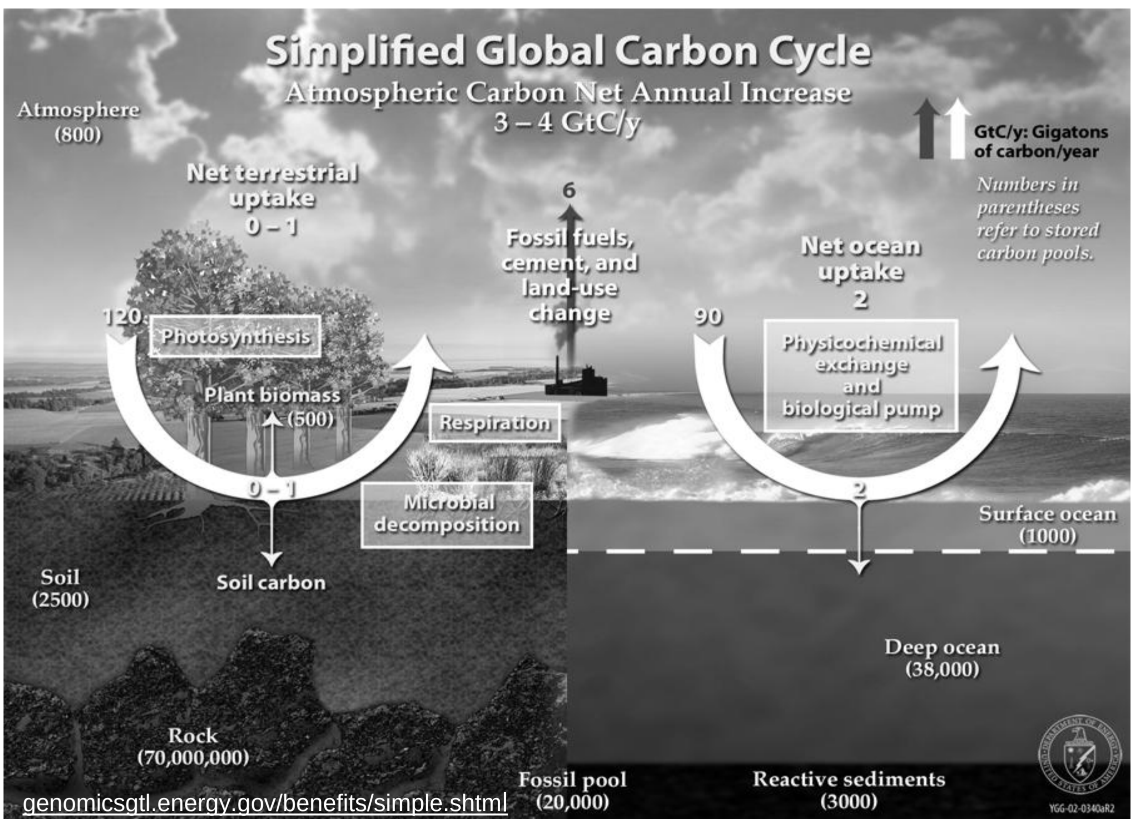

Figure 1: The above figure shows the simplified global carbon cycle. The numbers in parentheses represent how much carbon each sink in the biosphere is able to store. Altering the number and capacity of these sinks could severely alter the Global Carbon Cycle.

Forests as Carbon Sinks

Studies suggest that land ecosystems sequester approximately 1/3 of anthropogenic emission in plant and soil pools (Schimel et. al 2001). Recent studies have been conducted to illustrate the important role that forests play as global carbon sinks. Forests are a critical component of the global carbon cycle, storing over $1x10^5$ metric tons of carbon in biomass, detritus, and soils (Gough et al., 2007). In the northern hemisphere, forests sequester almost 10% of current global fossil fuel C emissions (IPCC, 2007).

Soil respiration and Bole Respiration

Measuring tree respiration for above ground biomass and soil respiration for below ground biomass can be an indicator of the overall capacity of specific trees (and ultimately the overall forests) to be carbon sinks. Within forest ecosystems, the soil plays a critical role in the global reeducation-oxidation cycle of carbon (Lou & Zhou, 2006). Forest soils contain more than 70% of the terrestrial world's soil carbon pool (Kobizar, 2006). Carbon influences that capacity of soils to retain water and nutrients and therefore to support plant production (Lou & Zhou, 2006). Soil respiration plays a critical role in regulation atmospheric CO_2 concentration and climate dynamics on Earth (Lou & Zhou, 2006)**.** It is possible that global warming could increase global soil respiration, releasing more CO_2 into the atmosphere that will ultimate intensify the effects global warming (Schimel et al., 1994). However, little is known about the effects of carbon cycling in disturbed forest systems. Since many of our forests have been modified by natural and anthropogenic disturbances, it is imperative that we understand the consequences on carbon cycling (Concilio, 2006). Thus, objectives of this experiment are to assess the effects that a selected disturbance (tree girdling) has on rates of tree respiration; more specifically soil respiration and bole respiration.

Methodology

This study was conducted at the FASET sight, located on the grounds of the University of Michigan Biological Station in Pellston, MI. The site is 33 ha in size. The site is a mixed-deciduous forest at the end of its secondary succession stage. The tree demographics of the forest include: bigtooth aspen *(Populus gradidentata*), trembling aspen *(Populus tremulodides*), red oak (*Quercus rubra*), paper birch (*Betula papyyrifera*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and American beech (*Fagus grandifolia*), the understory is dominated by bracken fern *(Pteruduyn aquilinum*).

Aspen trees were the focus of this experiment. In order to be used during this study, the trees had to meet certain criterion: the trees had to spatially close to other Aspen trees and other biota could not be in close proximity (1 m) of the selected plot. After the criteria was exhausted for the given site, six plots containing four to six Aspen trees were selected for this study. The plots were grouped by twos and a block design was utilized for experimental purposes. One plot in each block was established as controls. The other plot in the block was designated as the experimental plots. All of the trees in the experimental plots were girdled (the complete bark was removed to the depth of the xylem around the circumference of the tree) using a professional pruning chainsaw. A crowbar was then used to separate the bark from the tree.

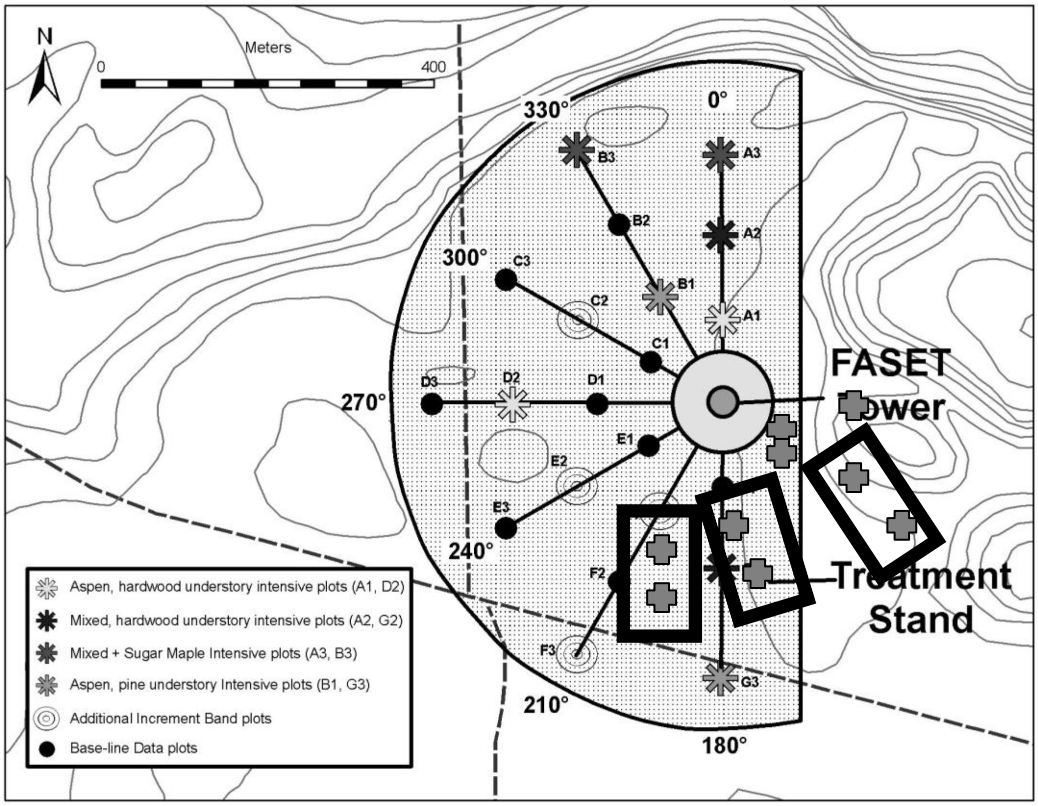

Figure 2: A schematic showing the locations of the plots within the block design at the Forest Acceleration Succession Experiment (FASET) site at University of Michigan Biological Station. The crosses within the blocks are plots that were girdled in July 2007. The crosses outside of the blocks represent trees that were girdled in March-June of 2007, and July of 2006.

Soil Respiration

Set-Up

0.10 m diameter polyvinyl chloride (PVC) collars were utilized for the experiment. A metal apparatus with an equivalent diameter and circumference as the PVC collars was used to cut into the soil, to create a guide for the collars. This assured that the collars could be securely placed in the soil with little disturbance occurring in the soil. Three collars were spatially arranged within each of the six plots to provide the most accurate readings of soil respiration within each plot. It was determined that collars could not be within 0.5m of each other or a tree in the plot.

Measurements

A series of point measurements were made at various times throughout a time period of a twenty-six days to analyze soil respiration trends. For each plot the temperature of the soil, the air temperature, and soil respiration were measured using the LiCor 6400 Portable Photosynthesis System. The moisture of the soil was also measured using Hydro Sense soil moisture probe. To begin the measurements, the LiCor 6400-08 gasket was placed on its side and allowed to calculate the ambient CO_2 levels of the environment just above the forest floor. The respiration rates were calculated by placing the 6400-09 Soil CO_2 Flux analyzer gasket on the 0.10m diameter PVC collars that were previously positioned in the soil within the plots. By placing the 6400-09 attachment on the collar, a dynamic closed chamber system was created. CO_2 levels were scrubbed down-using CO_2 scrub that was a part of the Li-Cor machine- to 20 ppm below the ambient CO_2 level and allowed to gradually rise to the same amount above the ambient CO_2 level. Three cycles were performed for each measurement. The rate at which the CO_2 rose was calculated and the efflux value was able to be determined (since the rate of CO_2 increase is proportional to the CO_2 efflux). This procedure was repeated for each collar within the plot to get an average efflux rate of each plot.

Bole Respiration

Set-Up

A single tree within each plot was selected to have PVC collars attached to its bole. Trees across plots were selected based on their DBH relative to a selected median DBH (28cm). This was done in order to rule out differences in respiration rates due to tree size. The 0.10 m diameter PVC collars were shaved down on two opposite ends using a bit drill and a grinding attachment. This allowed the traditionally symmetrically round PVC collars to be able to fit more securely on the boles of the trees. Silicon caulk was used to adhere the collars to the trees. For control trees, only one collar was placed on the tree bole. For the experimental trees, collars were placed above and below the girdled area, as well as directly on the girdled area. The volume of each collar was measured.

Measurement

Bole respiration was measured using the LiCor 6400 with a custom cuvette as an attachment. The custom cuvette was attached to the 0.10 m diameter plastic PVC collars that were sealed to the tree boles using wire springs. As in soil respiration measurements, the CO_2 levels were scrubbed down below the target level and allowed to rise. The rate at which the CO_2 increased was used to calculate the efflux value. The procedure was repeated for all collars on each tree bole. Respiration rates were analyzed.

***Trees that were previously girdled in March, April, May and June of 2007, as well as trees that were girdled in July 2006 were also monitored for their soil and bole respiration rates.

Results

Soil Respiration

Initial efflux values of all six plots were taken on day 197 of the year to get baseline values. The trees in the experimental plots were girdled on day 198. The average efflux values across the six plots varied greatly over the seven time points when the measurements were taken. The efflux values between plots in a block were compared. A strong trend-of the efflux value of the treatment plot within each block being lower than the control-was consistently observed in each block. The beginning efflux values ranged from 10.53 to 6.93 (μmoles/m^2/sec), with the ending values ranging from 10.75 to 4.15 (μmoles/m^2/sec) (Figure 3). Among the trees that were previously girdled before July 2007, average efflux values were just as variable. Efflux values ranged from 10.64 to 5.94 (μmoles/m^2/sec) when the readings first began. At the end of the experiment, the average efflux values ranged from 8.21 to 6.77 (μmoles/m^2/sec) (Figure 4).

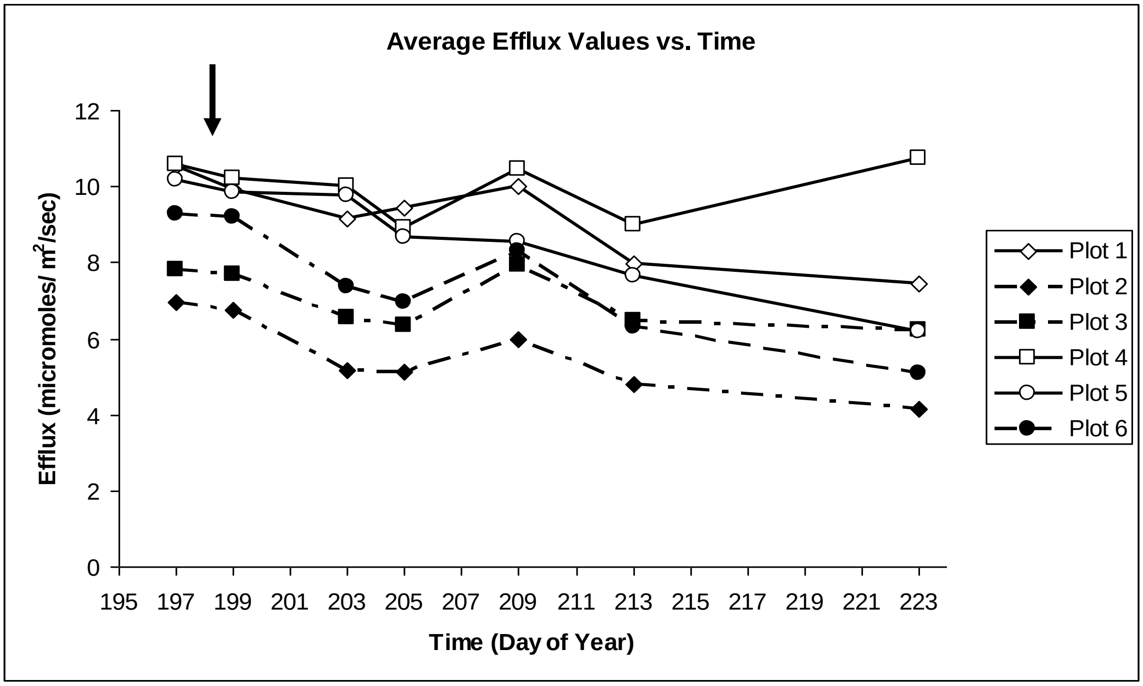

Figure 3: The above graph shows the average efflux values of plots that were girdled in July 2007. The arrow represents the day the trees in the experimental plots were girdled (day 198). The black dashed lines represent the treatment groups. The range of efflux values can be seen among the plots.

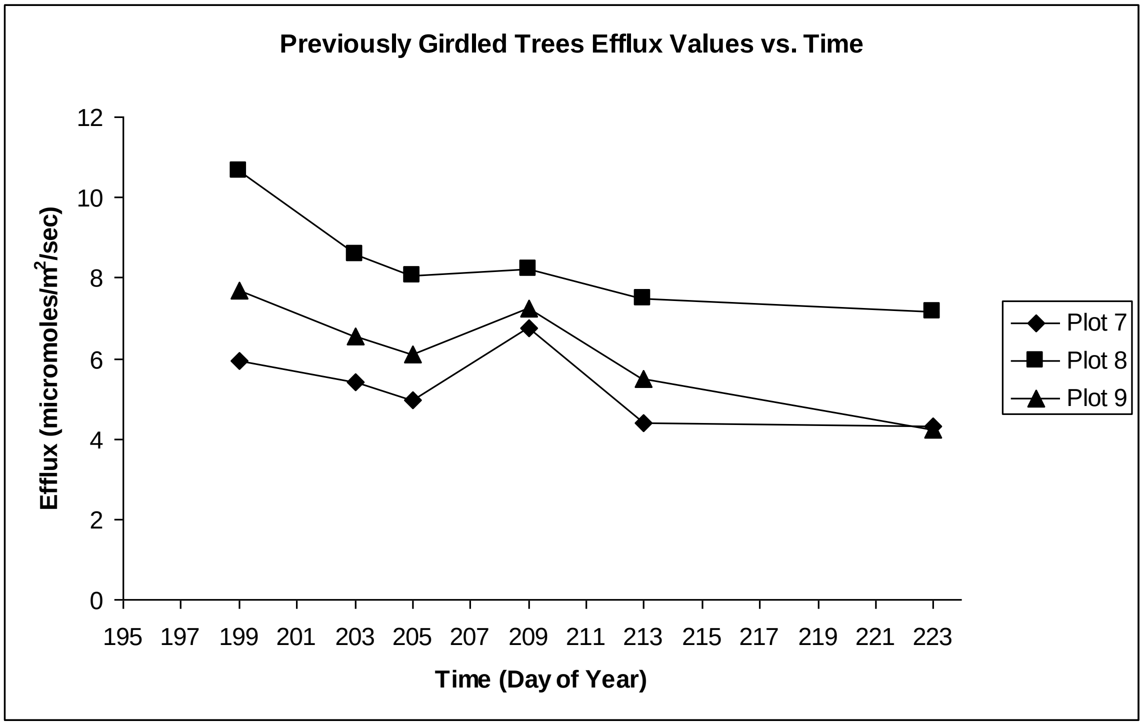

Figure 4: The above graph reflects the average efflux values for trees in plots that were girdled before July 2007.

Soil temperature and soil moisture were measured to ensure that that differences in efflux rates could not be attributed to changes in these to variables. And if these two factors did affect efflux value, then the effect should be seen across plots. Soil temperature measurements were found to be consistent throughout the plots. On the average day the temperature differences between plots did not exceed 0.8˚. Day 213 had the highest temperature difference with a 1.79˚ difference between the highest and lowest plot (Figure 5).

Soil moisture measurements-like temperature-remained consistent among the plots during the time of the experiment. Day 197 had the greatest difference in soil moisture between plots (from 10% to 7%). The sharp jump from day 205 to 209 can be attributed to a heavy downpour that occurred on day 208, however it should be noted that soil moisture increased across all that plots (Figure 6).

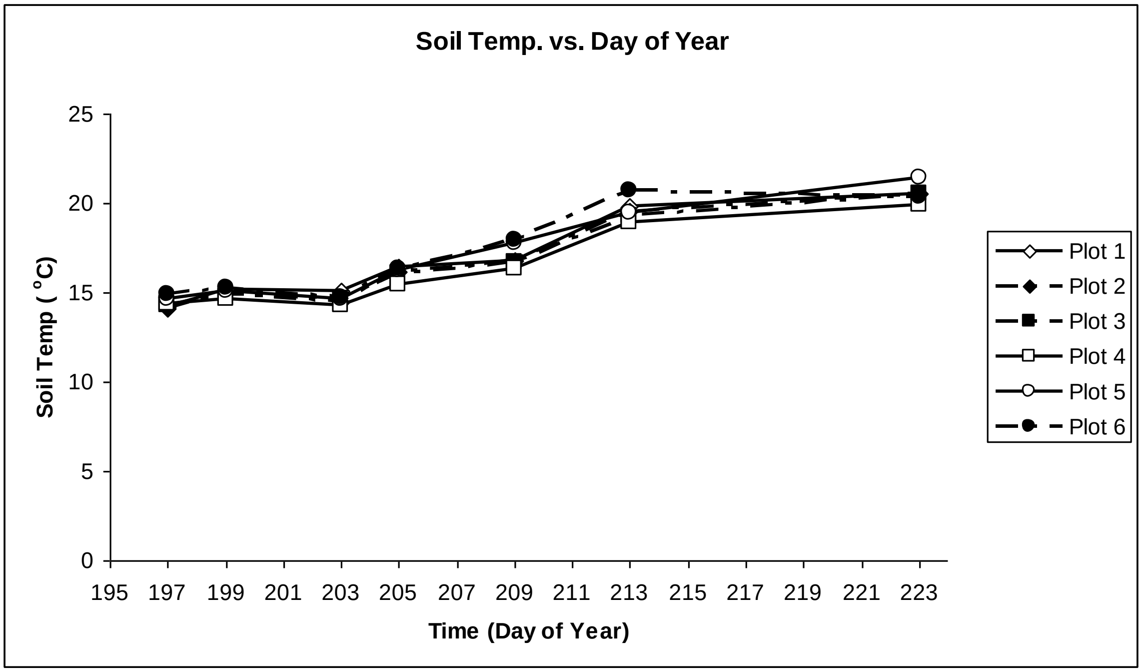

Figure 5: The above graph reflects the soil temperature for each plot at the designated time intervals during the experiment. The soil temperature had minimal variation amongst plots on days measurements were taken.

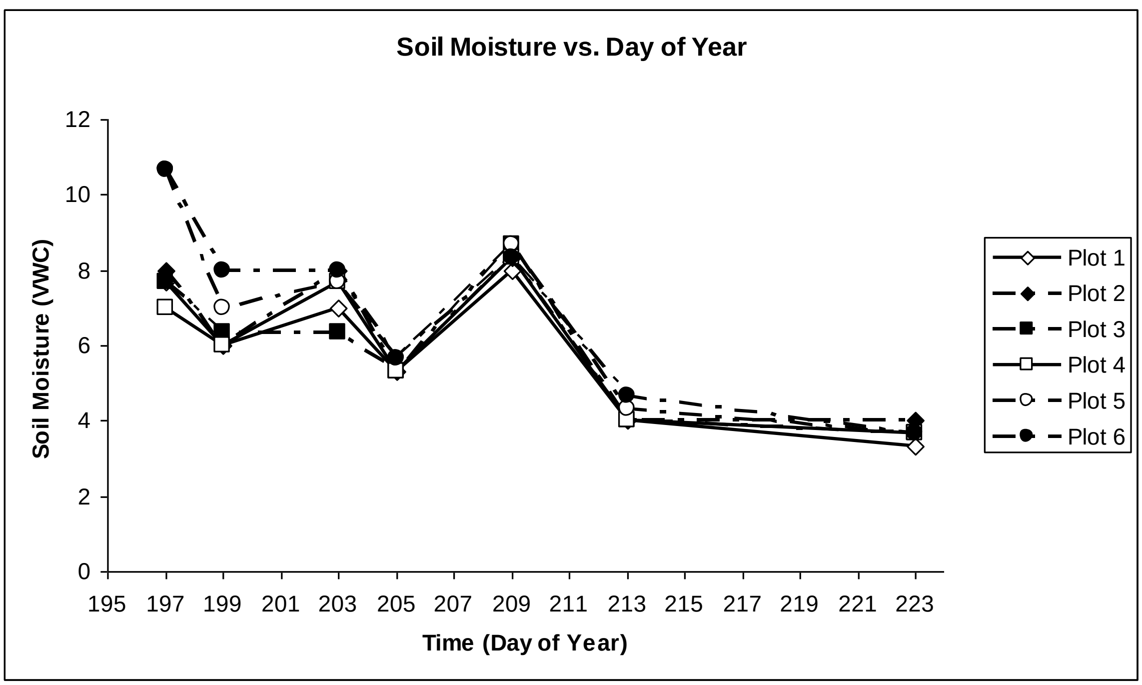

Figure 6: The above graph reflects the soil moisture for each plot at the designated time intervals during the experiment. Overall, soil moisture had minimal variation amongst plots days measurements were taken.

In addition to the average efflux values of each plot being calculated, the % change in efflux from the beginning date of the experiment at each time interval was also calculated, by comparing the two values in the form of a proportion (Figures 7 and 8). In plots two, three, and six (the experimental groups) a stronger trend of declining efflux values was seen when compared to their control plots one, four, and five, respectively. In order to determine the trend's significant, a paired t-test was performed on days 203, 205, 209, 213, and 223. The p-values were found to be: 0.014, 0.124, 0.890, 0.051, and 0.111 (respectively). Thus, the only day that yielded a significant p vale was day 203. In addition to calculating the change in efflux values by plot, the average change in efflux by all control and all treatment plots were also calculated. By the end of the experiment, the average efflux value of all the control plots was 78% of their baseline efflux value; while the average efflux value of all the experimental plots was 65% of their baseline efflux value (Figures 9 and 10).

Absolute Values for Efflux Change From Start Date of Experiment							
	Day 197	**Day 199**	**Day 203**	**Day 205**	**Day 209**	**Day 213**	**Day 223**
Plot 1	1.00	0.94	0.87	0.90	0.95	0.76	0.71
Plot 2	1.00	0.98	0.75	0.74	0.86	0.69	0.60
Plot 3	1.00	0.98	0.84	0.81	1.01	0.82	0.80
Plot 4	1.00	0.97	0.95	0.84	0.99	0.85	1.02
Plot 5	1.00	0.97	0.96	0.85	0.84	0.75	0.61
Plot 6	1.00	0.99	0.80	0.75	0.89	0.68	0.55

Figure 7: The above chart reflects the absolute values of the efflux changes within plots. This value was calculated by creating a proportion between the efflux values each plot at a given time point and the original starting value. This was created to account for each of the plots having different baseline efflux values (the values taken from all plots before the experimental treatment of girdling was performed).

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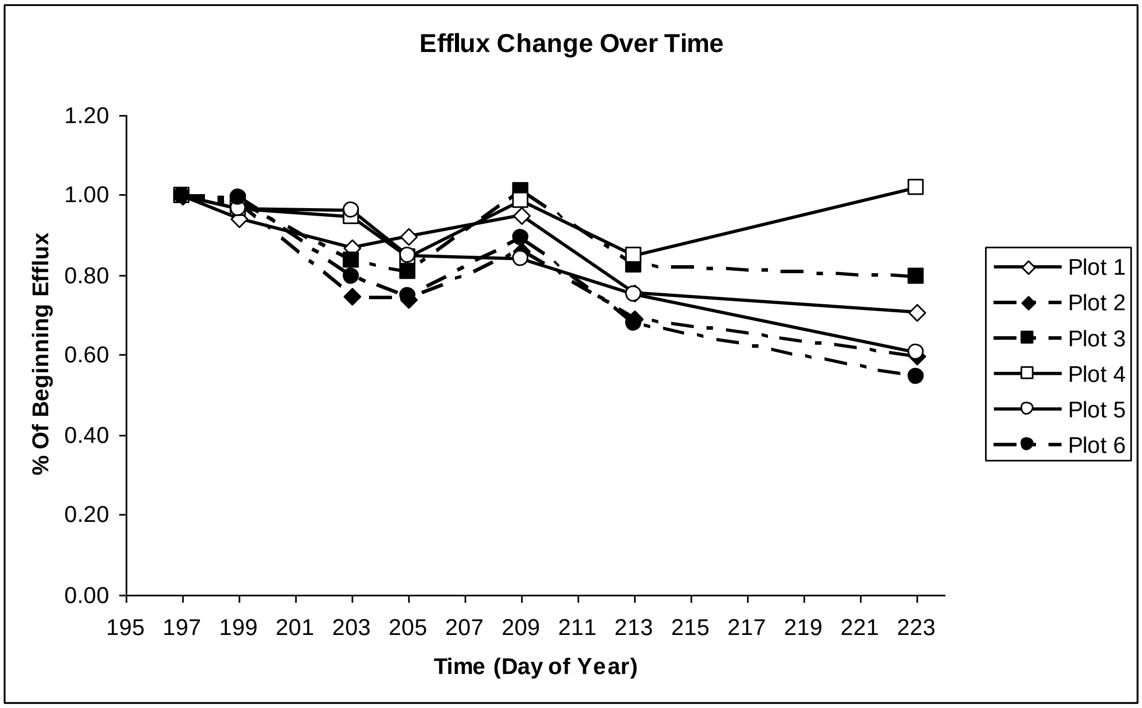

Figure 8: The above graph is a pictorial representation of the data contained in figure 7. The graph reflects the efflux changes at each time point in comparison with the beginning values of each plot.

Average Change in Efflux Values (Control vs. Experimental)							
	Day 197	Day 199	Day 203	Day 205	Day 209	Day 213	Day 223
Control	1.00	0.96	0.93	0.86	0.97	0.79	0.78
Experimental	1.00	0.98	0.80	0.77	0.92	0.73	0.65

Figure 9: The above chart represents the absolute proportional values of change in efflux in control and experimental plots.

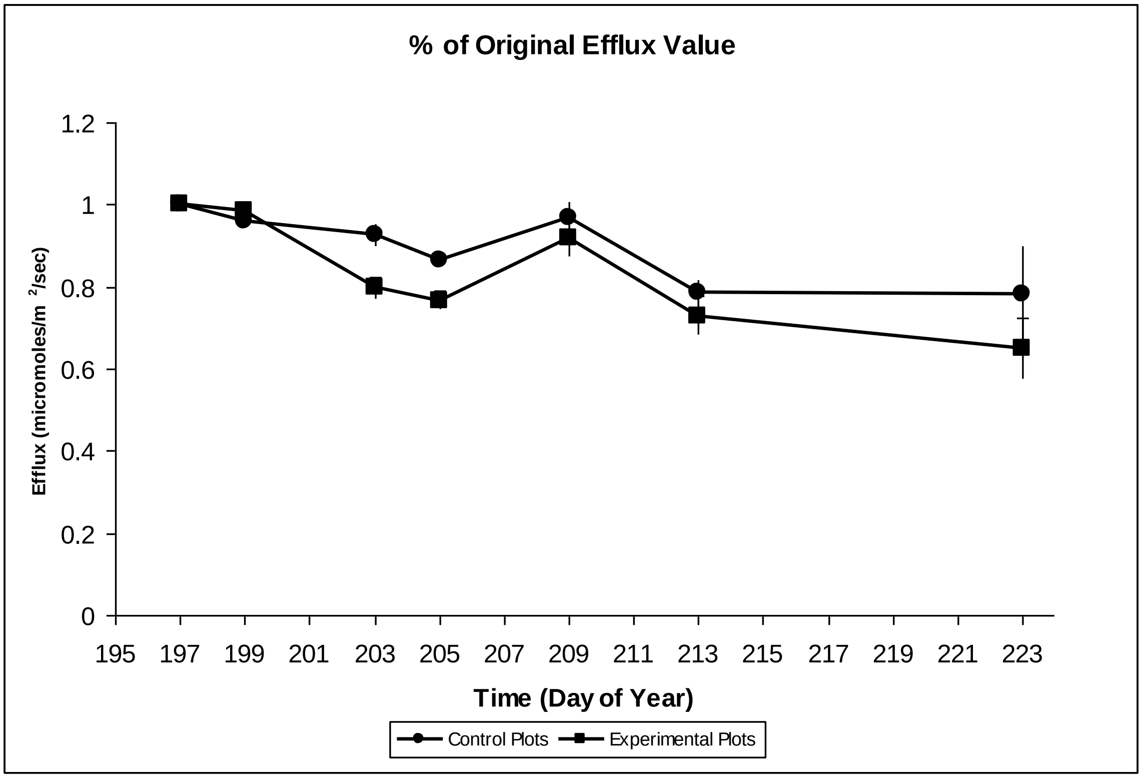

Figure 10: The above graph represents the average change in efflux values in control plots and experimental plots.

Bole Respiration

The measurements for bole respiration were only able to be taken two times. Thus, the two values were averaged for data analysis. The efflux values of the selected trees varied greatly. However, all but one of the trees followed the trend of having the highest efflux value for above the girdled area, the next highest value below the girdled area, and the lowest efflux value on the girdled area. The trees that were girdled before July 2007 had substantially higher efflux values above the girdle when compared to the trees girdled in 2007 (Figure 11). The average efflux value for above the girdled area on trees that were girdled before July 2007 was 9.86 μmol/m^2/sec; whereas the average efflux values for those girdled in July 2007 was 4.67 μmol/m^2/sec. As for below the girdled area, those trees that were girdled in July 2007 were slightly higher than those girdled at other times with values of 3.11 μmol/m^2/sec and 2.33 μmol/m^2/sec, respectively. In regards to the girdled area, the trees girdled in July 2007 had a slightly higher value than those previously girdled at 1.90 μmol/m^2/sec and 1.38 μmol/m^2/sec, respectively. The control tress had an average efflux value of 4.44 μmol/m^2/sec (Figure 12).

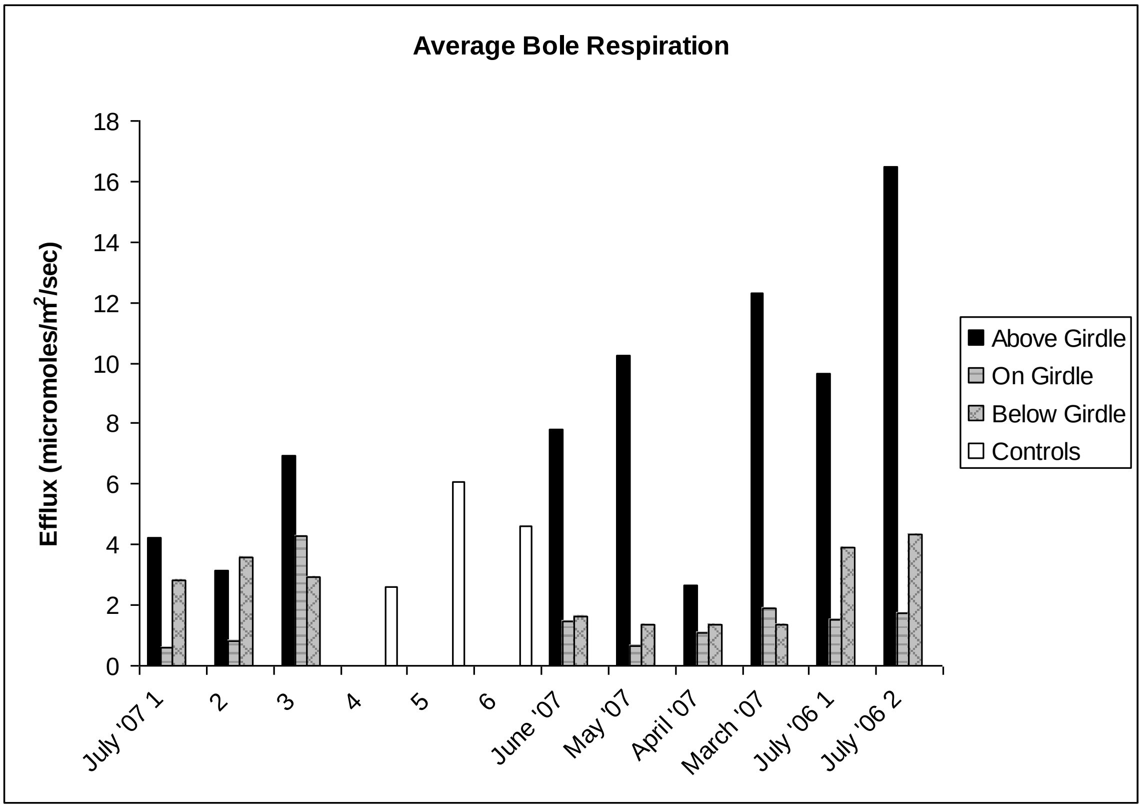

Figure 11: The above graph shows the efflux values for different areas on trees that were girdled during different times. Most of the trees follow the trend of having the highest efflux value for the area above the girdle, followed by the area below the girdle with the next highest efflux value, and on the girdle areas with the lowest efflux values. The trees girdled before July 2007 have a substantially higher efflux rate above the girdle.

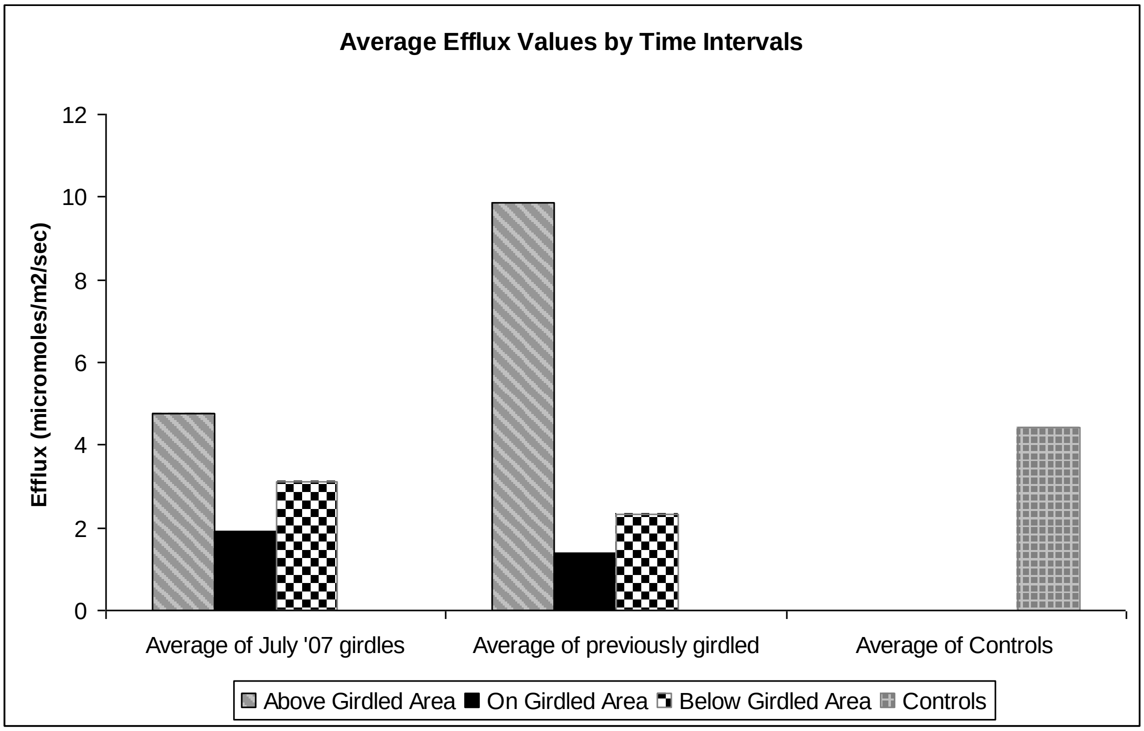

Figure 12: The above graph compares the average efflux value of those tress girdled in July 2007 with those previously girdled and control trees. Trees girdled in July 2007 have a lower efflux value above the girdle when compared to trees that were previously girdled. However, trees girdled in July 2007 have higher efflux values for areas both below the girdle and on the girdle when compared to previously girdled trees.

Discussion and Conclusion

Soil Respiration

When the effects of temperature and soil moisture were factored out, there was a strong trend that indicated that a decrease in respiration was due to the treatment effect of girdling. This could be seen in the fact that when there was no change in temperature or soil moisture between time points, that there was a greater efflux decrease in treatment groups. However, when soil moisture or temperature did change there was a noticeable response in efflux values. The spike in efflux values between day 205 and 209 was due to an increase in soil moisture following a heavy rain. When efflux values were measured after the effects of a soil moisture increase had subsided, the trend was again observed. Within individual blocks, the efflux values of the treatment groups were consistently lower than control groups. However, when a paired t-test was performed, significant p values were not consistently found for all data points. The strong declining efflux trend along with the non-significant p-values creates much ambiguity as to the exact effects of the girdling.

It will be interesting to continue to monitor whether the same declining efflux trend is observed over time, because two possible scenarios could occur. Either the declining efflux trend will continue due to the death of the tree's roots. This would leave only the respiration of the microbes in the soil, thereby greatly decreasing the CO_2 respiration levels. Or another possible scenario could occur that involves the decaying roots becoming fertilizer for the microbes, actually greatly increasing microbial respiration rates and therefore soil rates.

***Although soil respiration measurements were taken for plots 7-9 (trees that were previously girdled before July 2007), they were not included in the data, because there was no way to standardize their efflux, because a pre-girdle value was not available.

Bole respiration

Efflux values vary were found to vary greatly among tree, but this can be attributed to individual differences in the trees. All of the treatment trees had the highest average efflux values above the girdle when compared to on and below the girdle. Most of the trees had higher efflux values in the below girdled area than in the girdled area. For those that didn't follow the trend, confounding variables could be the reason why. For example, tree July '07 3 does not follow the trend. It was observed onsite that the tree itself was beginning to rot at the roots. Thus, it was hypothesized that the inside may also be rotting and the efflux values that were obtained were not that of the tree bole, yet the fungus decomposing the tree inside.

There was a greater difference between efflux values on the three areas of trees that were previously girdled than those girdled this year. This observation is consistent with physiological mechanisms that govern trees .Because girdling inhibits the pathway that sucrose (the respiration substrate) utilizes to travel to the roots, as the plant produces more sucrose it builds up large amounts above the girdled area because it cannot penetrate the barrier that has been created by the girdling. Therefore, the higher efflux values above the girdle in trees that were previously girdled is consistent with this mechanism. The fact that those trees girdled in July ’07 had higher efflux rates on the girdle and below the girdle is also consistent with the mechanism. Over time, it would be expected that any sucrose that was available on the girdle and below the girdle will eventually be depleted, ultimately lowering their efflux values. It is also interesting to note that the trees that were girdled in July ’06 have higher efflux rates below the girdle than those that were girdled in March-June 2007. This could possibly be because the tree has depleted its sucrose supply below the roots, but is now tapping into its starch supply for energy. If this is the case, once the starch supply is exhausted there will be no more substrate available, and one would then expect the efflux values to reflect no respiration.

Another interesting point of discussion is the complex root system of Aspen trees. Aspen trees are able to produce suckers from its roots. Therefore when girdling the trees it is important that all of the suckers receive the same treatment, otherwise it may be possible for other suckers to send nutrients to those suckers that have been affected by girdling. In this experiment all suckers were spatially close to each other, and therefore were girdled in experimental plots.

Future works should include continued measurements of both soil and boil respiration with a greater sample size. Also, a tree core should be taken from tree July ’07 3 to determine if the reason the tree did not follow the predicted trend and had higher efflux values on the girdled area is indeed due to decomposition within the tree.

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