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THE IMPACT OF REFORESTATION ON SOIL TEMPERATURE

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ABSTRACT: *As the world's largest source of organic carbon, soils play an important role in the cycling of carbon in our atmosphere. The amount of carbon stored in the soil is dependent on the rate of photosynthetic uptake by plants and the rate of plant and microbial respiration, which are in part a function of soil temperature. Within Central NY the landscape is presently succeeding from fields back to forests. How this change in land cover will impact the underlying soil temperature is an important question to consider as our global climate continues to change as a result of increasing carbon dioxide concentration in our atmosphere. Using a hillside in Hamilton, NY as a case study, our research attempts to determine the differences in soil temperature between forests and fields. Results demonstrate that during the fall (Nov 12-Dec 25) and winter (Dec 26- Mar 31) forested soils were warmer than field soils. The spring (Apr 1- May 31) showed an opposite trend with field soils being warmer than forested soils. The field soils also show greater temperature variations than the forest soils. These results suggest that during the fall and winter the soil in the forests have the potential to release more carbon than the field soils. As succession occurs on abandoned fields in Central New York, soil temperatures will change, which will affect their capacity to cycle organic carbon.*

INTRODUCTION

The temperature of the soil impacts many important environmental processes such as the rate of plant growth, distribution of plant species, and its capacity to store carbon. As the world's largest source of organic carbon, soils play an important role in the cycling of carbon in our atmosphere (Jobbagy and Jackson, 2000). Carbon is either stored or released from the soil depending on the rate of photosynthetic uptake by plants and the rate of plant and microbial respiration (Trumbore, 1997). The rates at which plants photosynthesize as well as the rate of microbial respiration are in part controlled by the temperature of the soil they are growing in (Lloyd and Taylor, 1994). One of the controls on soil temperature, and consequently the amount of carbon it contains, is land cover type.

Areas of Central New York are succeeding from fields back to forests (Flinn et al., 2005). How this change in land cover will impact the underlying soil temperature is important to consider because it will influence the soil's capacity to store carbon. This becomes especially significant when placed in the context of global climate change. As the 2001 Intergovernmental Panel on Climate Change (IPCC) report states, increased emissions of CO_2 and other greenhouse gases are causing a global rise in annual air temperatures by 0.6 ± 0.2^{o}C. Because just a 10^{o}C increase in soil temperature doubles its capacity to produce carbon (Witkamp and Frank, 1970), a more complete understanding of the controls on soil temperature is important in our understanding of the consequences and solutions to global climate change. Using a hillside in Hamilton, NY which is located in the heart of Central New York as a case study, our research examines the differences in soil temperature between fields and the succeeded pine forests between November 12, 2004 and May 31, 2005.

LITERATURE REVIEW

A great deal of research has sought to answer the question of how land cover change impacts the storage of organic carbon. Research on the topic of soil temperature has been going on for nearly 80 years with one of the earliest studies dating back to a 1926 dissertation by Tsi-Tung Li at Yale University (Li, 1926). This study was one of the earliest to link soil temperature and land cover changes. Results from the study showed that forested sites were cooler than the field sites in the summer and warmer in the winter. Artificially denuded sites and fields showed greater temperature variation in the winter than forests. Several years later MacKinney (1929) investigated the importance of leaf litter on soil temperature. His findings from this winter time study showed that litter acts as an insulator, keeping the soils warmer in the winter by trapping radiant heat. This blanketing effect also decreased the diurnal range in soil temperature especially in the spring. Land cover was also shown to be important by Fritts (1961) in his analysis of summer soil temperature in both forested and cleared soils. His results demonstrated that during the summer, forest cover lowers the maximum soil temperature when compared to the fields. Fritts also documented the importance of aspect on soil temperatures. A report by Jeffrey (1963) again links soil temperature and land cover, citing that vegetation type influenced the temperature of the soil. He analyzed the impacts of a White Spruce stand which has an open canopy, a Balsam Popular stand with a more closed canopy, as well as a clear cut forest. The results of this study suggested that crown cover influences the temperature of the soil by trapping radiant heat released.

Witkamp (1966) showed that the rate of CO_2 evolution was positively correlated with soil temperature. This was an important development in the study of soil temperatures and land cover because it explains the significance of such research. Witkamp (1969) investigated this topic further by showing that there were daily variations in CO_2 evolution that were also positively correlated with daily soil temperature cycles. This led to the conclusion that an increase in temperature by 10^{o}C results in a doubling of the amount of CO_2 produced by the soil (Witkamp and Frank, 1970). As we place this in the context of global climate change these results are of great significance. Harte et al. (1995) addressed the issue of global climate change in the context of soil temperature. Their study shows how an increase in atmospheric temperature could impact various aspects of soil micro-climate. Soils under dense vegetation were influenced less by the artificial warming than the bare soil. A study by Trumbore et al. (1996) related soil temperature and the rate of CO_2 evolution citing that increases in soil temperature caused an increase in the rate of CO_2 evolution into our atmosphere. Similar to early research, Schaetzl and Tomczak (2001) investigated the effect that cleared land had on soil temperatures during the winter in a snowy climate similar to our study site. They found that cleared land resulted in colder soil temperatures and greater variability. Recently, a study was conducted in England by Bellamy et al. (2005). They found that since 1978 soils had been losing organic carbon at a rate of 0.06%yr^{-1}, suggesting that as global temperatures rise organic carbon from the soil is being released.

Although many studies have been done on both land cover and its influence on soil temperature as well as the impact of soil temperature on CO_2 evolution few have linked the two together in the context of local land cover and global climate change. The research reviewed above suggests that significant linkages exist between land cover, soil temperature, and carbon cycling. In order to begin to assess how soil temperature might change during secondary succession we measured the differences in soil temperature between forests and fields.

STUDY AREA

Our study site is located on the southwestern side of a 106.3 meter (349 ft) tall hill in Hamilton, NY (Madison County). This region has a temperate climate with an average annual air temperature of 5.2^{o}C. The average daily high over the course of one year is 12.3^{o}C and the low is 0.3^{o}C (Hanna, 1981). Located in a region greatly impacted by lake effect snow, Hamilton receives an average annual snow fall of 2.8 meters. The average first frost date over a ten year period (1971-1981) was September 24. During the same ten year period the average last day of freezing temperatures was May 20 (Hanna, 1981). In terms of the geology and soil genesis of the area, the effects of the last glaciation which ended about 12,000 years ago can still be seen today. The large continental ice sheet covered the tallest hills in Hamilton and was responsible for the layer of till deposited on the exposed bedrock surfaces as the ice thinned and the glacier retreated. The soil at our study site was developed within this layer of till and consists of large carbonate rock fragments surrounded by fine, clay-rich sediment.

METHODS

In early November, we placed 22 Hobo data logging temperature probes on the south western facing slope of a 106.3 meter (349 ft) tall hill in Hamilton, NY in order to assess the temperature differences between land cover types (see Figure 1). These temperature logging probes enabled us to assess the temperature differences between fields and forests. The probes were set to record temperature at six hour intervals giving us four readings per day. Each probe was buried in a sealed PVC capsule to prevent moisture damage. We buried them at various elevations and land cover types, at a depth of 30cm. We determined that 30cm was an ideal depth because it is deep enough to avoid results dominated by the diurnal temperature range but close enough to the surface so that it is still within the organic carbon rich layer. Because aspect influences soil temperature we kept it constant locating all of our sites on the south-west slope of the hill. Statistical analysis showed that variations in elevation between the forest and field were not significantly different at a 95% confidence interval. The land cover types chosen for the study were field and forest with the forested land consisting of mostly pines (*Pinus strobes* and *Pinus resinosa*) and deciduous trees (*Fagus Americana* and *Acer saccharum*), as this best reflects the different land cover in this area. At the end of May we retrieved the probes. The data were downloaded onto the computer and formatted for analysis. We divided the data by land cover type (forest vs. field), and mean soil temperature was calculated for each of the seasons in the study period (fall, winter, and spring) as well as the average for the total sample period at each of the sites. The seasons were divided by pedothermic period which Schaetzle and Tomczak (2001) describe as periods of consistent trends in temperature and variability. We divided our pedothermic periods as follows, fall (Nov 12-Dec 25), winter (Dec 26-Mar 31), and spring (Apr 1- May 31). We also calculated standard deviations for these time periods. We then produced a data chart comparing soil temperatures by land cover. Further, we used linear regression to assess the relationship between the topologic variables and soil temperature.

RESULTS

Mean soil temperatures for the entire study period (Nov 12 –May 31) were warmer in the fields than the forests (see Table 1). The fields' mean soil temperature for this period was 4.09^{o}C while the forests' was 3.57^{o}C. The field soils had greater variation than the forested soils with standard deviations of 3.31 and 2.43. Of the three seasons examined in this study the forested soils were warmer in both the fall and the winter, but not significantly. The mean soil temperature in the fields during the fall was 4.67^{o}C and the forest was 5.10^{o}C. The wintertime mean soil temperature for the fields was 1.30^{o}C while the forest was 1.37^{o}C. The spring marked the greatest difference in mean soil temperature between the forest and the field with mean field temperature at 8.13^{o}C whereas the forest has a temperature of 5.89^{o}C. The variability in temperatures was determined by the standard deviation and showed substantially more variability in the fields during the fall and spring (see Table 1).

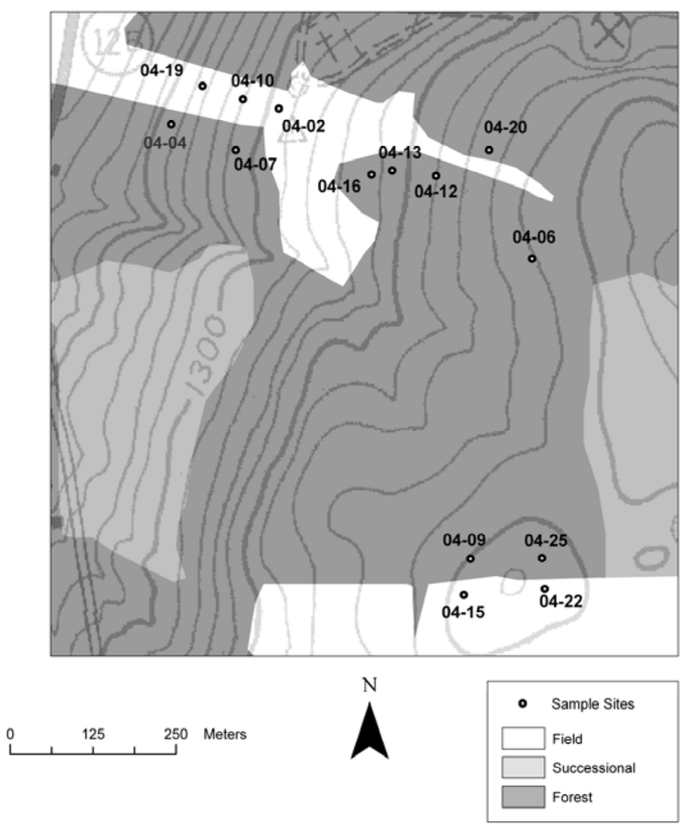

Figure 1. Study area and sample sites locations

Table 1. Seasonal soil temperatures for both the forests and the fields

		Mean Temperature (°C)							
Site ID		(Nov 12-Dec 25) Fall		(Dec 26-Mar 31) Winter		(Apr 1-May 31) Spring		(Nov-May 31) Total	
Field	Elevation, ft (m)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
04-19	1233 (376)	4.21	1.41	0.52	0.46	7.18	2.72	3.33	3.34
04-10	1284 (391)	4.46	1.39	1.03	0.28	7.68	2.62	3.78	3.21
04-02	1313 (400)	5.40	1.53	1.70	0.39	7.46	1.95	4.25	2.87
04-20	1471 (448)	5.19	1.59	1.86	0.41	8.12	2.01	4.47	3.04
04-15	1512 (461)	3.90	1.53	1.03	0.43	9.55	2.59	4.22	4.01
04-22	1538 (469)	4.87	1.50	1.68	0.43	8.78	2.35	4.51	3.40
Avg.	1391[A] (424)	4.67[A]	1.49	1.30[A]	0.40	8.13[B]	2.37	4.09[B]	3.31
Forest	Elevation (ft)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
04-04	1241 (378)	4.67	1.53	0.87	0.30	5.75	1.97	3.17	2.60
04-07	1330 (405)	5.44	1.24	1.60	0.61	5.39	1.73	3.58	2.25
04-13	1404 (428)	4.85	1.41	0.52	0.52	5.53	1.63	3.18	2.45
04-16	1405 (428)	5.21	1.54	1.05	0.57	5.09	1.68	3.18	2.39
04-12	1446 (441)	5.04	1.31	1.75	0.33	6.87	2.02	4.01	2.61
04-06	1464 (446)	5.71	1.42	2.13	0.31	6.43	1.73	4.20	2.33
04-09	1517 (462)	5.13	1.42	1.70	0.37	5.95	1.70	3.73	2.30
04-25	1538 (469)	4.78	1.37	1.36	0.42	6.12	2.00	3.54	2.51
Avg.	1418[A] (432)	5.1[A]	1.41	1.37[A]	0.43	5.89[B]	1.81	3.57[B]	2.43

[A] Not significantly different at a 95% confidence interval

[B] Significantly different at a 95% confidence interval

DISCUSSION

These results clearly demonstrate the importance of land cover and its impact on soil temperature. The results we obtained in our study further support the idea that forests insulate the ground from the cold in the winter and from solar radiation in the summer causing warmer winter time soil temperatures and cooler spring time temperatures. As past literature suggests these differences in temperature are a result of the blanketing effect of both the forest floor litter and the forest canopy. During the winter there was no significant difference between the field and forest temperatures but the absolute temperature difference suggests that the forests were slightly warmer than the fields during this period. Together the canopy and the forest floor litter trap radiant heat released by the underlying soil, keeping it warmer during the winter. Figure 2 shows that the fields cooled faster and to a lower temperature than the forests in the fall. Because of the insulating effect of the forest canopy it takes longer for the underlying soil to cool. This insulating effect also shades the forested soils from incoming solar radiation. Because of their greater exposure to solar radiation the fields heat up faster than the forests as is evident in Figure 2. The variability of the fields is greater than that of the forests (Table 1). For example, as shown in Figure 2 the line representing the field temperatures is more variable than the line representing the forests.

There are notable daily high and low dips in the line which represent the diurnal change in soil temperature. The line representing the forests does not show these pronounced changes in diurnal temperature which means that the forest soil temperatures are more stable throughout the day which parallels the results obtained by MacKinney (1926).

As soil temperature changes so does its capacity to produce CO_2 (Witkamp, 1969). This inverse relationship between soil temperature and the soil's capacity to produce CO_2 is the result of decreased rates of microbial composition in colder temperatures. Because fall soil temperatures in the forests are warmer than the fields they have the potential to release more carbon and consequently cycle more CO_2 into the atmosphere. Winter is the season of lowest microbial activity which results in less CO_2 production. As our results suggest, the slight variation between forest and field temperatures during the winter causes the forest to release only slightly more CO_2 during this time. The spring marked the period of greatest difference between soil temperatures. Springtime fields consequently have a lesser capacity to store carbon. The difference between forest and field temperatures was 2.24^{o}C. The significance of such a temperature change is evident in the fact that with every 10^{o}C increase in soil temperature its capacity to produce carbon doubles (Witkamp and Frank 1970). The difference for the entire study period was 0.52^{o}C meaning that the fields overall have a greater potential to release carbon into the atmosphere than the forested soils.

CONCLUSION

As the land in Central New York succeeds from fields into forests the capacity of the underlying soil to store carbon has clearly been altered. The succeeding forests will both absorb carbon from the atmosphere to become part of its standing bio-mass and the soils will increase their capacity to store carbon since the average soil temperature in the forests was lower than that of the fields. Since soils are the world's largest source of organic carbon and land cover changes are occurring all around the world, whether as deforestation in the Amazon Rainforest or succession in Central New York, an understanding of the consequences of such changes in land cover is important because of the issue of global climate change.

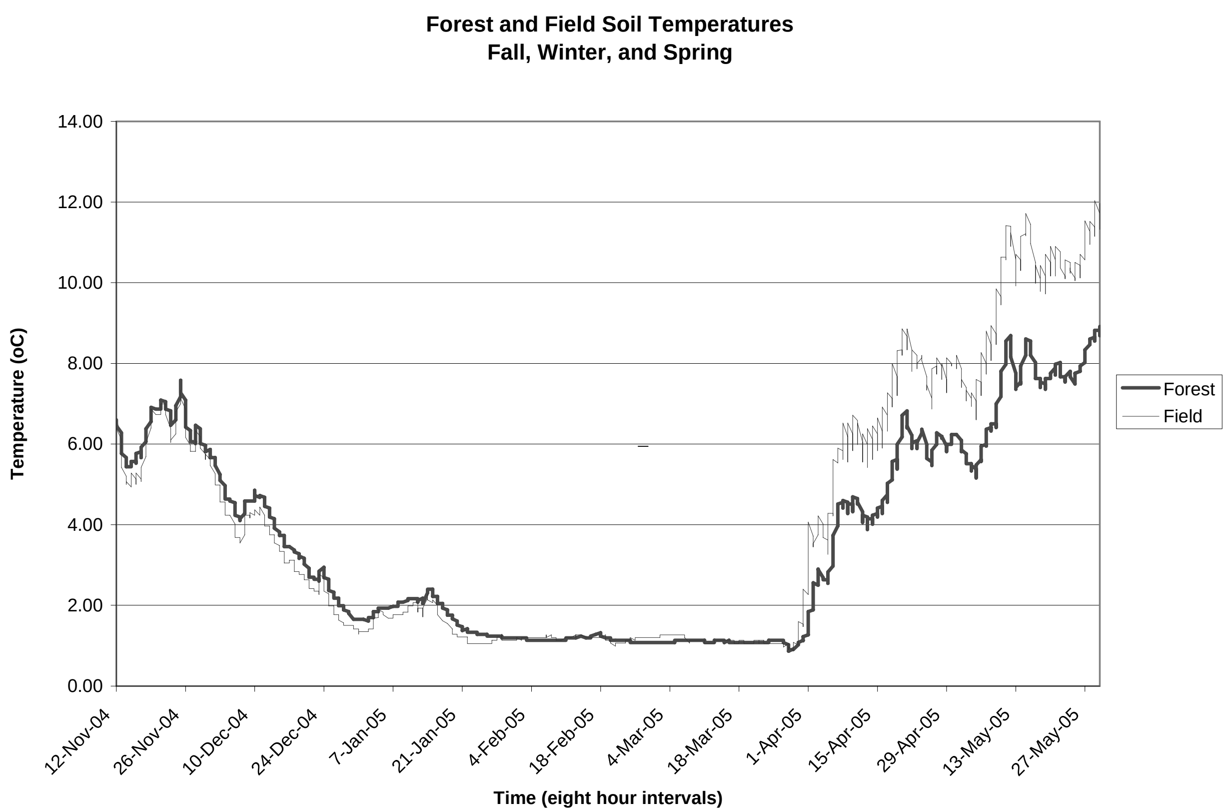

Figure 2. Changes in soil temperature from November 12 through May 31

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