Carbon Assimilation and Its Variation among Plant Communities

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Introduction

Currently, global warming remains a large concern to society. The elevated amounts of greenhouse gases are of significant concern to us because it is like part of the cause for the steady rise in global temperature measured over the last several decades, which is in turn, the driving force of many global issues. Today, many people and businesses are attempting to become more carbon neutral by reducing their carbon output while potentially increasing the amount of carbon sequestered. In order to increase the quantity of carbon assimilated, the culture of actively growing plants on the green space available is required. Green space is a useful resource because it potentially can contain a variety of photosynthetic plants which require carbon dioxide for growth. The goal for the research project this summer was to measure the sum of carbon dioxide assimilated at PCCI during the 2009 growing season, and in the process, and to compare the Gross Primary Productivity of plant species and communities comprising PCCI to identify those communities which could be expanded to further increase the quantity of carbon assimilated, if possible.

The amount of carbon assimilated is directly related to the Gross Primary Productivity (GPP) of a plant. The GPP of a given plant can be found by measuring the apparent photosynthesis rate of that plant. The photosynthesis rate measures micrograms of carbon dioxide absorbed per meter squared per second. Apparent photosynthesis rate (GPP) is absolute photosynthesis rate after subtracting the carbon dioxide produced from aerobic respiration. Classically, extensive photosynthetic measurements have not been taken in agricultural applications, but less so in natural areas. Ultimately, this information proves very useful in a physiologically based, qualitative measurement of a natural area's productivity.

The objectives of this research were to compare the apparent photosynthesis rates of the 13 representative or predominant plant species (20 species total) covering PCCI's landscape, to compare the GPP of the seven plant communities comprising PCCI's landscape, and to empirically estimate the GPP of PCCI greenspace.

Methods

In order to test natural areas, plant communities were delineated by defining general plant communities and the predominant plant species and percentage of that species for each plant community were identified. In doing so, predominant plant communities were targeted, tested, and compared. The communities described at PCCI were Prairie, Field, Shrubby Field, Early Succession, Late Succession, Mixed Swamp and Sedge/Fen. These seven communities were significantly different in species composition. The plant communities were distributed among many different areas of the Pierce Cedar Creek property as a function of such factors as soil type, water availability, and use history.

Within each plant community, a minimum of six GPS points were identified and served as replicates for that particular community. With the replicates (GPS points) spread over the entire PCCI property, were attempted to accurately estimate the species composition and percentage by plant community type. At each GPS point, we looked at the species composition in each of the four cardinal directions, and estimated species composition at three levels of the canopy (upper, middle, lower). For example, when looking north at a 90-degree vector, we looked at the plant species comprising the top, middle and lower canopy and then recorded what percentage each species made up of that specific canopy level. This large range of data allowed us to better determine the dominant plant species of a given plant community. After going to each GPS point and determining percent species composition, we calculated the species and genus that comprised the largest percentage of greenspace over the entire PCCI property. The plant types that comprise the majority of the foliage at PCCI were Oak, Maple, Black

Cherry, White Ash, Beech, Cedar, Tamarack, C3 grasses, C4 grasses, Sedge, Goldenrod, Autumn Olive and Elm.

To determine the GPP of these predominant plants, we used a LICOR 6400XTR gas exchange meter to measure the photosynthesis rates of individual leaves at a variety of light levels. With a leaf clamped into the infrared gas analyzer (IRGA) chamber, the instrument would proceed to produce light at progressively decreasing intensity while recording the stable photosynthesis rate at each light level. This data, when placed in a graphical format, creates what is termed a Light Use Efficiency curve (LUE curves). The LUE curves show how much carbon uptake happens at given light level. As light level increases, the photosynthesis rate also increases and plateaus off from medium to high light levels, and ultimately drops off with excessively high light levels. Each leaf was tested at nine different light levels ranging from 2000 down to 0 W/m^2. We could then use the LUE curves to compare the photosynthetic capacity of plant species, or their ability to assimilate carbon, based on the shapes of each plants respective curve.

Now, with a way of determining the GPP (apparent photosynthesis rate) of a plant at a given light level, the last component required was data on how much light gets to a given plant's leaves in a natural ecosystem. This brings us to canopy-light interactions in the various plant communities comprising PCCI's property. In order to find these interactions, the first step was to take hemispherical photographs of each community's canopy. These pictures could then be analyzed by a computer software program (Gap Light Analyzer), which estimates the leaf area index (LAI) of each photograph, which is essentially a reflection of the number of leaf layers making up that particular canopy. Leaf layers are dependent on how dense leaf foliage was and the amount of light able to penetrate the canopy, to be transmitted through successive layers of leaves.

The second step in understanding the canopy-light interactions of a plant community was measured using a quantum sensor. The quantum sensor was used to measure how much light penetrated through each leaf layer of a given plant species. For example, direct light level was measure, then the amount of light that passed through a single leaf, and then the amount of light that passed through two leaves, and so on.

Lastly, the third step in dealing with the canopy-light interactions, dealt with how much light entered PCCI over the growing season. We uploaded solar radiation levels for every hour of every day (and night) between the dates of April 15 and August 9. With this data, we were able to determine specific carbon uptake rates at given time for a given plant species. We were then able to apply these specific assimilation rates to whole plant communities.

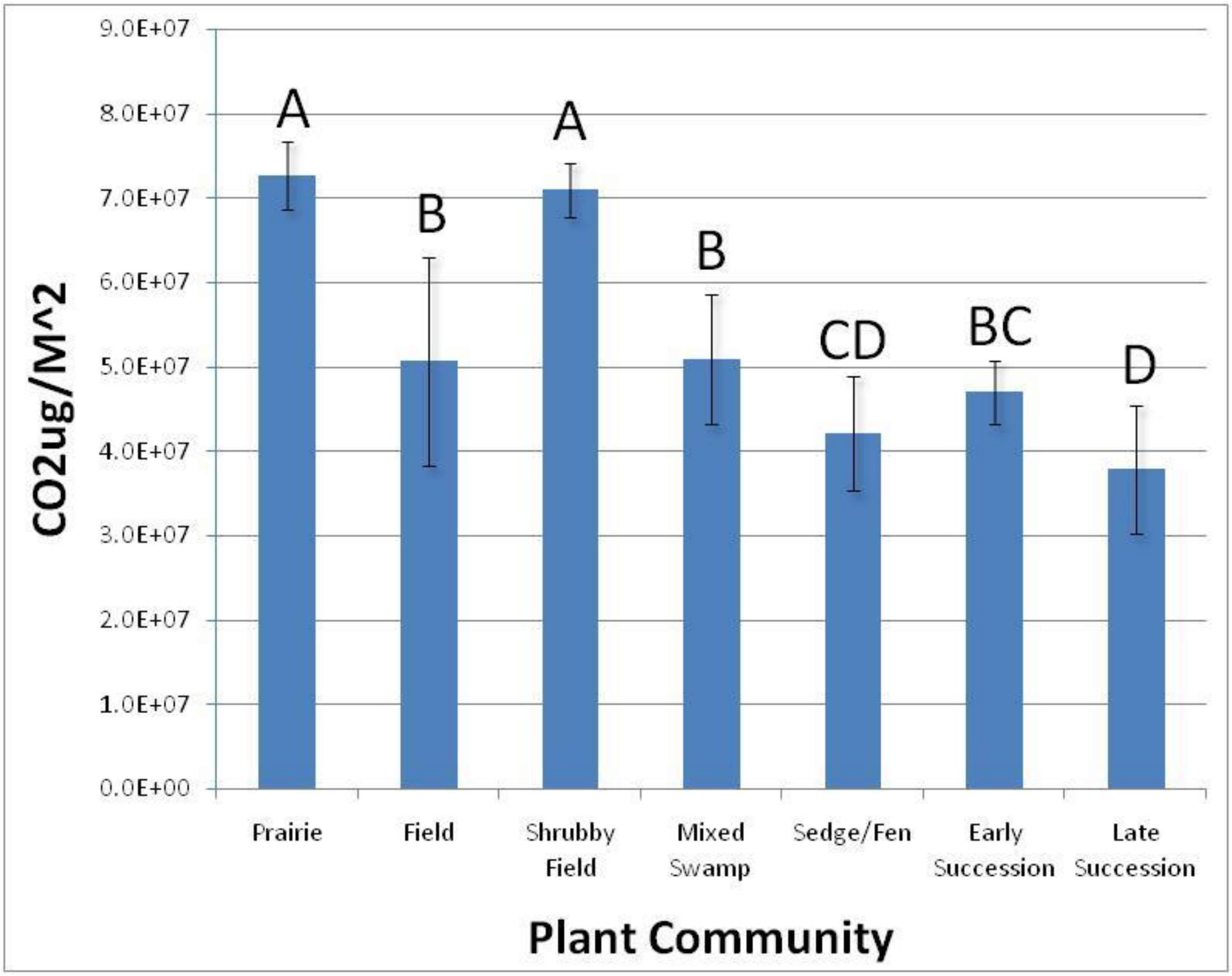
Taking a step back from all the complexities and details of the methods and materials listed above, it is simplest to understand our research process in terms of a four dimensional model. The first and second dimensions represent the distribution of the various plant communities across the land area of PCCI. That is where the GIS map came into play. Because there is no volume to the map; it is only a 2 dimensional plane. The third dimension comes into play when dealing with the canopy light interactions, or the depth and layering of various plant community canopies. Both, the leaf area index and light penetration of leaf measurements gave us quantitative data, which we then used to calculate the third dimension of the model. The fourth dimension adds the variable of time to the model. We had a three dimensional model of Peirce Cedar Creek Institute's property, but until we took into consideration hourly, daily, and seasonal differences in light level could we determine the productivity of the greenspace over a given time period. We obtained the variable of time by utilizing the hourly solar radiation levels recorded by PCCI's weather station. In sum, if we know how much light PCCI's greenspace obtains over the entire growing season, how much light each leaf layer gets in the canopy, what the composition is of each plant community at each layer, and how efficient photosynthesis is at those light levels for each plant species, then we can sum the total carbon assimilated across PCCI's landscape.

Results and Discussion

In response to our first objective, to compare the apparent photosynthesis rates of the 13 predominant or representative plant species, we created fourth order light use efficiency curves (LUE) for each of the measured plant species we tested. These light use efficiency curves are mathematical equations that describe the relationship between photosynthesis and light for each plant. The line equations are based entirely on actual measurements taken in the field, and there are statistical differences between each plant species measured. Each of the LUE curves had R^2 values of 0.96 or higher. So, if the variable x (the light level) is measured, then the variable y can be solved for, indicating the gross primary productivity of that plant at that light level.

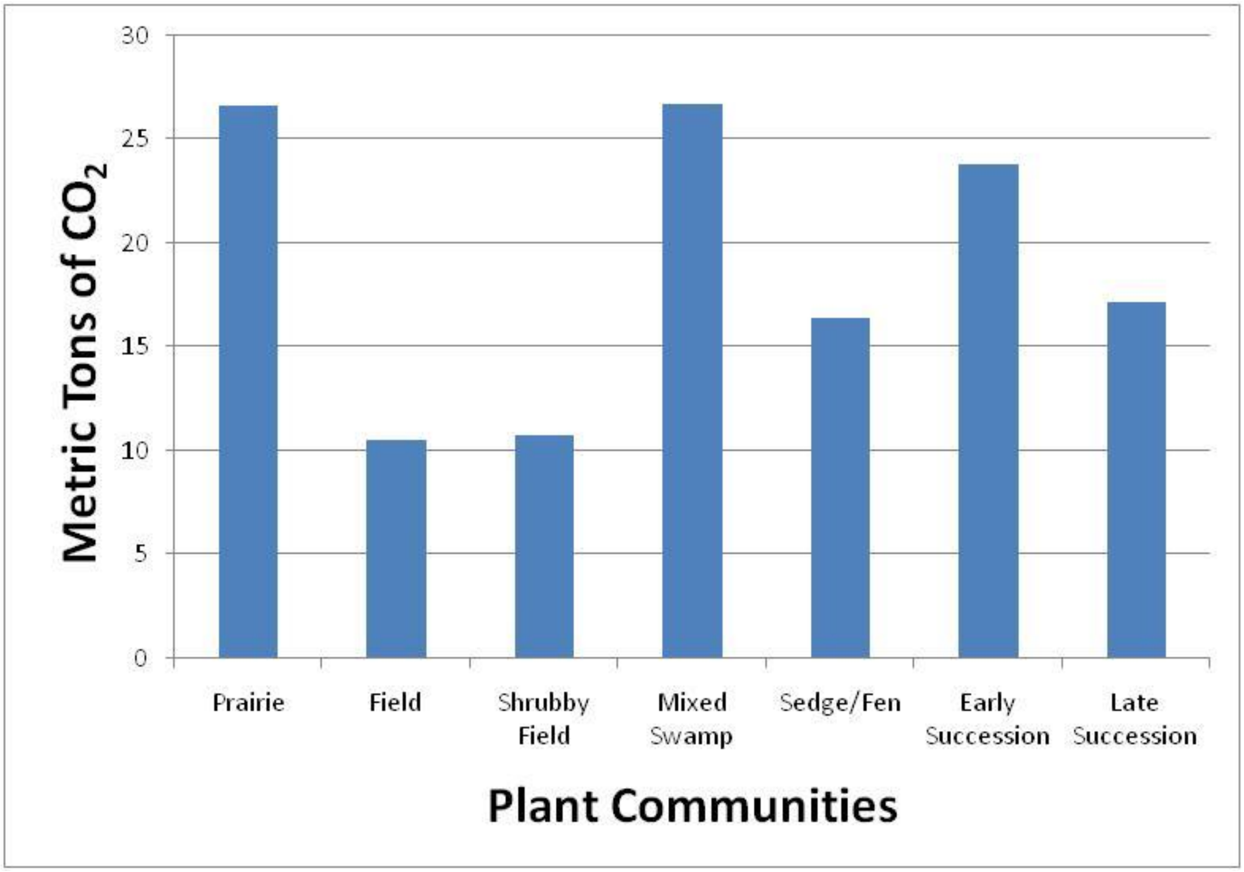
The second objective, to compare the GPP of the seven plant communities comprising PCCI's landscape, is presented in the graph below. Of the seven plant communities measured at PCCI, these are the rates of assimilation per m^2 at PCCI from April 15 to August 9. First of all, the prairies and shrubby fields have a considerably higher assimilation rate than the other plant communities. Furthermore, there is statistical significance between early and late succession forest, which is of interest, because this difference is supported by a substantial body of literature. Lastly, take note of the error bars, which were derived from the GPS replicates that were incorporated into our various plant communities. One error bar, in particular, that I would like to draw your attention to is the "Field" error bar. This large error bar on field might be expected as some of our field replicates were very patchy without much vegetation (reasonably representative of an early successional area), while other field replicates contained much thicker vegetation. In light of this graph, implications can be drawn as to which plant communities might be emphasized or restored in an effort to best decrease atmospheric CO_2.

Plant community CO_2 assimilation per m^2

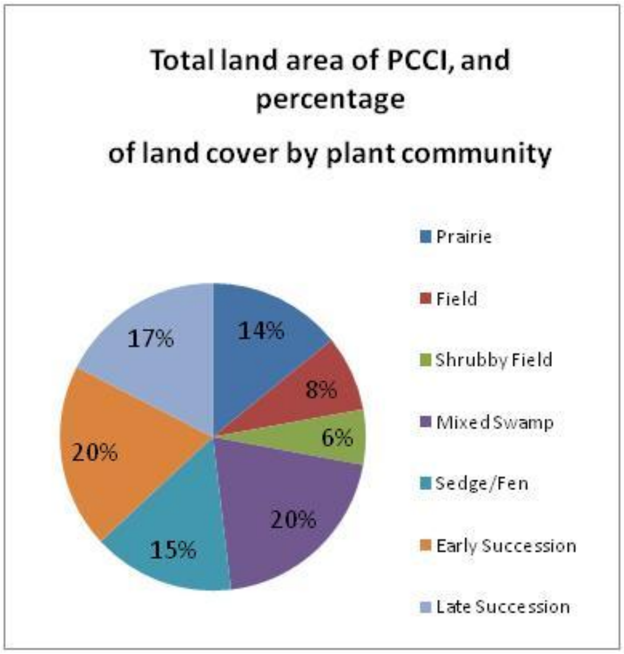


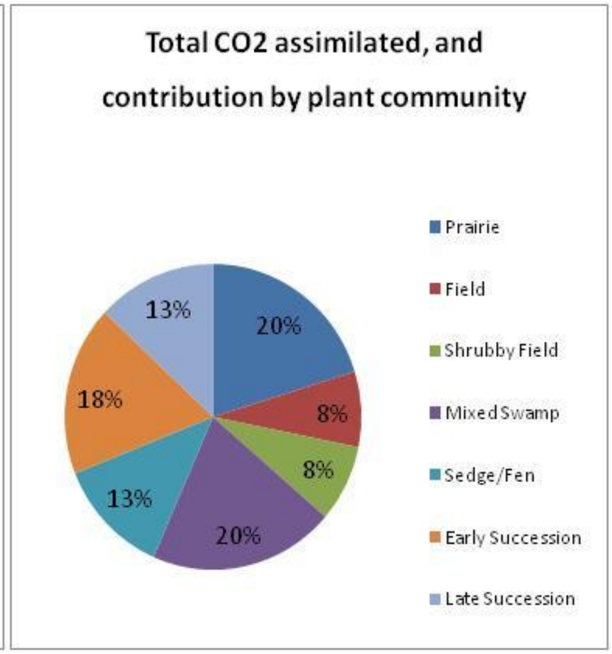
Up until this point we have been dealing with micrograms of CO_2; however, in order to address the third objective, to empirically estimate the GPP of PCCI greenspace, it is much more convenient to scale the data up to metric tons (MT) of CO_2. The graph below depicts the quantity of CO_2 assimilated at PCCI by plant community in MT. All together, 132 metric tons of CO_2 was assimilated at PCCI from April 15th to August the 9th. This graph may rather difficult to conceptualize, because we are combining the rate at which each plant community assimilates carbon by the total land area that makes up each plant community. Even so, this makes it easy to see which plant community types at PCCI have the highest (or lowest) CO_2 uptake rates.

Total CO_2 assimilated between April 15 and August 9, by plant community (MT)



To reflect these results more clearly, it may be better to see the contribution that each plant community made by percent. In the pie charts below, we have the total land area of PCCI reflected in the pie on the left side and the total amount of CO_2 assimilated by each of the plant communities after accounting for both rate and area on the right. The increase of prairie from 14% land area to a 20% assimilated CO_2 contribution reflects the idea that although a relatively small amount of PCCI's land area is comprised of restored prairie, it contributes a proportionately high quantity of assimilated carbon due to its high assimilation rate at the community level. In contrast, the decrease in late succession from 17% land area to a 13% assimilated CO_2 contribution indicates the opposite effect. Suffice it to say, there are management implications here. I surely don't mean that we should replace all the late succession forests with Prairies. Rather, maybe it would be beneficial to convert old overgrown fields with prairie, instead of simply allowing them to undergo natural succession as they otherwise would. In another case, autumn olive removal would in effect reduce the amount of carbon assimilated by the PCCI green space because it exhibits high photosynthesis rates. PCCI land managers could maintain these rates, however, even after removing autumn olive if these areas were restored as prairies.





In conclusion, this research enables PCCI to estimate its carbon footprint by comparing emissions with assimilation. If PCCI is in fact carbon negative, they might have a chance to place carbon credits on the stock market in an effort to making some money from their preservation of greenspace. Along the same lines, if PCCI is interested in increasing the amount of carbon assimilated by their greenspace, there are management initiatives that could be implemented to increase the rate at which their property assimilates carbon dioxide. With global climate change at our doorstep and carbon dioxide now being regulated as a pollutant, society will be increasingly interested in carbon neutrality. This research could be of importance in future discussions of terrestrial ecosystem management and assimilation potential.