Evaluation of photosynthesis rates of introduced and native species in a mixed grassland ecosystem

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Abstract: In an effort to gain an understanding of the environmental factors contributing to photosynthesis rates in the northern mixed prairie grasslands as a carbon sink, this study investigated the effects of location (either sloped or upland), soil moisture and species type on photosynthesis rates measured in the West Block of Grasslands National Park, Saskatchewan, Canada. The study was conducted during June and July of the 2004 growing season. The first ecosystem studied is the naturally occurring mixed grass prairie consisting mainly of June grass (*Koeleria gracilis*), needle-and-thread grass (*Stipa comata*), blue grama (*Bouteloua gracilis*), and western wheat grass (*Agropyron smithii*). The second ecosystem consists of the introduced species crested wheat grass (*Agropyron cristatum*). It was found that introduced species (*Agropyron cristatum*) located on the upland sites, had significantly lower photosynthesis rates, while the native species located on upland sites had the highest rates of photosynthesis. It was also found that the introduced species are located in areas of significantly higher soil moisture than the native species when soil moisture was measured with the soil moisture probe.

Introduction

Increasing atmospheric CO_2 concentrations and the potential for climate change have made global carbon balance an important scientific and political topic. Researchers believe that the photosynthetic process in terrestrial ecosystems will contribute to the lowering of anthropogenic CO_2 emissions (Goudriaan 1992; Taylor and Lloyd 1992; Ham and Knapp 1998; Lloyd 1999). Lloyd (1999) reviewed a number of studies that examined the relationship between atmospheric CO_2 concentrations and plant growth. In almost all cases the studies reported increased growth in response to increased CO_2 concentrations. This has been further supported by studies conducted in laboratory conditions. In a compilation of literature sources, Poorter (1993) reviewed the growth responses of 156 different plant species to a doubling of atmospheric CO_2 concentration and found that growth stimulation on average was approximately 37%. It can be concluded then, that since plants respond to higher levels of atmospheric CO_2 by producing more biomass, vegetation will contribute to the management of increasing atmospheric CO_2. However, neither of these studies, nor the articles they reviewed, focused explicitly on the productivity (as measured through CO_2 exchange rates) of different grassland species.

Given that grasslands comprise the majority of the grazing capacity of the world (Burke et al. 1989), a further reason to investigate grassland ecosystem productivity is because of its economic importance as a rangeland resource. Degradation and desertification of grasslands are becoming increasingly common problems due to intense agricultural activities (Li and Ji 2002; Archer 2004). To ensure that this natural resource remains viable, an understanding of the biological and environmental components contributing to grassland productivity is required.

Human activities, particularly those related to ranching have heavily modified the prairie landscape during the twentieth century (Kepner et al. 2000). The introduced species crested wheat grass (*Agropyron cristatum*), a C_3 species, was transplanted to the North American prairie landscapes from Siberia. Plantation was encouraged because of its rapid spread and establishment, high coverage and, therefore, ability to improve pastures and bind soils prone to erosion. However, this species is now considered a pest as it is very competitive with high rates of seed production (Ambrose and Wilson 2003), and tends to reduce species diversity in the native prairie where it is found (Christian and Wilson 2002). Furthermore, this species is resistant to typical methods of weed suppression; in a northern mixed-grass prairie location, four years of herbicide treatment did not affect the emergence of the crested wheat grass seedlings (Ambrose and Wilson 2003). A literature review on the long-term effects of crested wheat grass indicated that this particular species has significantly higher above-ground productivity, but significantly lower below-ground biomass when compared to several native species found in the mixed grass prairies (Lesica and DeLuca 1996). Because the above-ground biomass and as a result, photosynthetic material is greater for crested wheat grass than for native species, it follows that the photosynthesis for crested wheat grass is also higher than the native species. However, there is no research comparing the photosynthesis rates of the crested wheat grass to the native species. A study comparing the rates at which the various grass species remove carbon dioxide from the atmosphere would greatly contribute to this research field.

In an effort to quantify the mixed prairie grasslands as a carbon sink; this study will investigate the effect of various environmental and biological components on photosynthesis rates. More specifically, the objectives of this study are to 1) investigate the effect of location (sloped vs. upland) on photosynthesis rates; 2) investigate the effects of soil moisture on photosynthesis rates; and 3) examine differences in rates of photosynthesis between several different native grass species as well as one dominant introduced species found in Grasslands National Park.

Methods

The study area is located in the West Block of Grasslands National Park (GNP) and surrounding pastures, which is in southwest Saskatchewan, Canada (49º12', 107º24'). This area falls within the Great Plains, which are characterized by semiarid climate, flat landscape and large areas dominated by grass species (Coupland 1992). Grasslands National Park is further located within the mixed grass prairie, one type of biome found within the Great Plains. This biome is a transitional zone between tall grass and short grass prairie (Davidson 2000). The climate in the study area is semi-arid; winters are long, cold and dry while the summers are short, hot and comparatively wet (Environment Canada 2000). Average temperatures range from -12.4ºC in January to 18.3ºC in July, and the average precipitation is approximately 350 mm per year (Environment Canada 2000). The soils in the study area are brown Chernozemic clay loam soils (Saskatchewan Soil Survey 1992). The dominant native grass species found in the study site are June grass (*Koeleria gracilis*), needle-and-thread grass (*Stipa comata*), blue grama (*Bouteloua gracilis*), and western wheat grass (*Agropyron smithii*). A dominant introduced species included in this study is crested wheat grass (*Agropyron cristatum).*

Field data collection:

Data were collected in June and July of 2004. This was a preliminary study, and unfortunately was limited to only one growing season due to time and financial constraints. In June, a total of 18 randomly selected sites were visited. Of these sites, five were upland ungrazed, five were upland grazed and eight were sloped ungrazed. The field methods employed in this study were developed for this study in the previous year, for details on the development of these methods, please refer to Zhang at al. (2005). At each of these sites, two plots were set up with 100 m transects running perpendicular at north-south and west-east directions. Soil moisture and photosynthesis rates were measured along these transects at 20 m intervals. A total of 605 samples were collected during June. All of these samples represented only native species. During July, a total of four sites were visited. Two of the sites visited were located in upland sites with native species. The first site was a transect, where photosynthesis and soil moisture measurements were collected every 3 m to a distance of 381 m. The second site was a 49 × 49 m quadrat, where the samples were collected from 41 randomly selected locations. The third site was a 500 m transect along sloped land with native species, where the samples were collected every 10 m. The final location was an upland site dominated by the introduced species crested wheat grass. At this site, the soil moisture and photosynthesis measurements were collected every 3 m along a 20 m transect. During July, a total of 259 samples were collected. An LCPro (ADC BioScientific Ltd.) was used to measure the photosynthesis of the leaves. The soil moisture at each plot was measured using an Aquaterr moisture meter. The method of data collection changed between June and July because the current study is a component of a larger study being conducted, which had changed their approach. However, because the current study compiles the June and July data, and does not compare the two sampling methods directly, this should have no effects on the results.

Data pre-processing and analysis:

Using the method described by Stevens (1996), outliers located three standard deviations above and below the mean were identified and then removed from the photosynthesis dataset. To determine if this dataset was normal, the distribution was tested using four parameters (refer to Figure 1). First, the Kolmogorov-Smirnov test resulted in a significance value of 0.2; there is no difference between the data and a normal distribution, which indicates that the data are normally distributed. The same conclusion was derived from the Shapiro-Wilk test (a=0.211). As well, the skewness (0.245) and kurtosis (-0.195) also indicated the data are normally distributed. Tukey's post hoc Analysis of Variance (ANOVA) was used to test for significant differences in photosynthesis rates between site locations (upland locations with native species, upland locations with introduced species and sloped locations with native species). Although the soil moisture data were not found to be normally distributed, it was related to photosynthesis rates using Pearson's correlation coefficient employing the methods described by Ebdon (2000). An independent samples *t* test was used to compare the soil moisture of areas of introduced species with areas of native species, also using methods described by

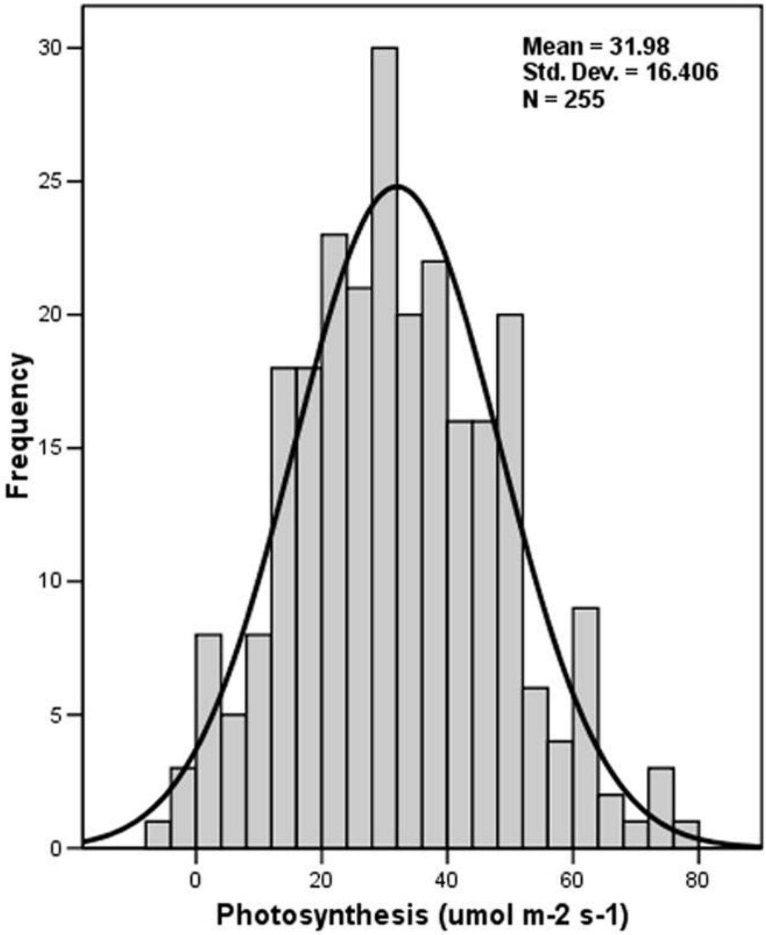

Figure 1: *Histogram of photosynthesis samples.*

Ebdon (2000). Tukey's post hoc ANOVA was also performed to investigate differences in rates of photosynthesis between grass species.

Results

Location differences:

A one-way ANOVA comparing photosynthesis rates by location and ecosystem type, found that upland sites with introduced species had the

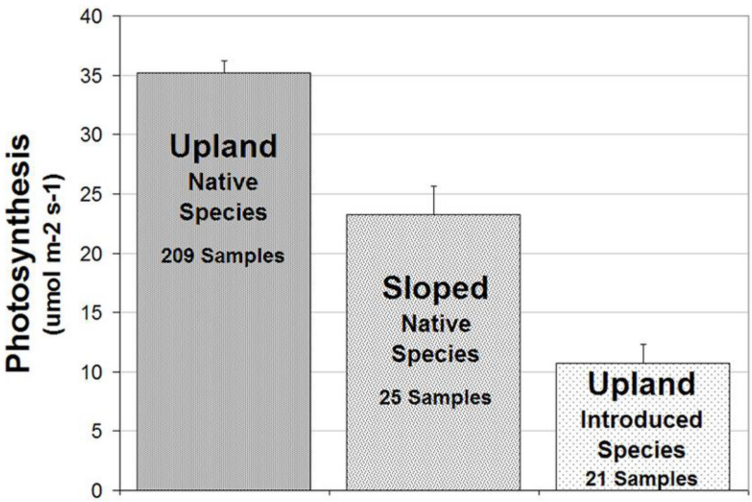

Figure 2: *Mean photosynthesis rates with standard error bars by site location.*

lowest rates of photosynthesis, sloped sites with native species had higher rates, and upland sites of native species had the highest rates of photosynthesis ($F_{2, 252}$ = 31.07 (p < 0.001)). Tukey's post hoc analysis showed that each of these groups is significantly different from one another (Fig. 2).

Soil moisture differences:

There was a small significant negative correlation found between the photosynthesis rates and the soil moisture (r = -0.23, p < 0.001) using Pearson's correlation analysis. When comparing the soil moisture of areas of introduced species with areas of native species, it was found that the introduced species are located in areas of significantly higher soil moisture ($t_{32.461}$ = -5.58, (p < 0.001)). The mean soil moisture measurements for areas of native and introduced species are presented in Table 1.

Table 1: *Mean soil moisture rates for native and introduced species.*

Species	Mean (% of maximum)	Standard Deviation
Native	78.02	9.29
Introduced	85.29	5.27

Species differences:

It was found that the introduced species crested wheatgrass (*Agropyron cristatum)* has significantly lower rates of photosynthesis than all other species measured ($F_{4, 250} = 12.91$; $p < 0.001$). Tukey's post hoc analyses divided the species into groups based on their mean rates of photosynthesis, displayed in Table 2. Thus, Group 1 consists of the introduced species crested wheat grass and has a significantly lower rate of photosynthesis than all of the native species. Group 2 consists of the following species: western wheat, June grass, needle and thread grass, and blue grama (*Agropyron smithii*, *Koeleria gracilis*, *Stipa comata* and *Bouteloua gracilis* respectively), all of which are native to the mixed grass prairie. These species were grouped together because they do not have statistically different mean rates of photosynthesis.

Table 2. *Mean rates of photosynthesis for different species.*

Grass Species	N	Group 1 (mean photosynthesis $\mu mol/m^2/s^1$)	Group 2 (mean photosynthesis $\mu mol/m^2/s^1$)
Crested Wheat Grass	21	10.71	
Western Wheat	48		31.16
June Grass	15		33.97
Needle and Thread	18		40.01
Blue Grama	15		47.53

Summary and Conclusion

The finding that crested wheat grass photosynthesizes significantly less than indigenous species found in Grasslands National Park indicates that the indigenous species make for a better carbon sink. In areas where this aggressive species is found, it often becomes the dominant species, as evident by the observation that some upland areas were almost exclusively crested wheat grass. This implies that with the spread of this introduced species, the northern mixed grass prairie is becoming a less efficient carbon sink. Although not statistically significant, another interesting find was that blue grama, which is the only C_4 species included in this study, had the highest rates of photosynthesis of all the native species. Had this study been extended into August, perhaps we would have found that this difference would become more exaggerated, as the C_4 species are more suited to function in higher temperatures than C_3 species.

The finding that the upland and sloped locations were associated with different photosynthesis rates is likely due to different types of plants making up the each of these communities, and each of these plants having slightly different rate of photosynthesis (Lloyd 1999). As well, the photosynthesis rates of upland crested wheat grass communities were found to be significantly lower than the photosynthesis rates of upland native species. The establishment of the different plant communities across the landscape is a result of a combination of different environmental factors such as soil fertility, moisture availability and slope aspect. This is further confirmed by the finding that soil moisture was found to be significantly higher in areas with introduced species compared to areas with native species. The concentration of native species in low moisture areas could be because the native species flourish in well-drained soils, but is more likely a result of competition from the aggressive introduced species, crested wheat grass (Ambrose and Wilson 2003).

In conclusion, although crested wheat grass is known to have larger above-ground biomass than native species (Lesica and DeLuca 1996), it is intuitive that this species should also have a larger quantity of photosynthetic material and therefore higher photosynthesis. However, this was not found to be true for this study, crested wheat grass photosynthesizes significantly less than the native species found in Grasslands National Park.

Further research:

Due to financial and time restraints, this study had a limited data collection span. Further investigation of the change in photosynthesis rates throughout the growing season, particularly for the introduced species, would provide more thorough information about photosynthesis.

To further understand the mixed grassland ecosystem, the link between the photosynthesis data with other biophysical factors, such as available CO_2, humidity, and photosynthetically active radiation, should be investigated. Relating these findings to remotely sensed images would be beneficial in that it would provide information about large areas, and allow for the construction of a model that could estimate the overall photosynthesis rates of a mixed grassland ecosystem.

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References

AMBROSE, L.G. and WILSON, S.D. 2003 'Emergence of the introduced grass *Agropyron cristatum* and the native grass *Bouteloua gracilis* in a mixed-grass Prairie restoration' *Restoration Ecology* 11 (1), 110-115

ARCHER, E. 2004 'Beyond the "climate verses grazing" impasse: using remote sensing to investigate the effects of grazing system choice on vegetation cover in the eastern Karoo' *Journal of Arid Environments* 57, 381-408

BURKE, I.C., YONKER, C.M., PARTON, W.J., COLE, C.V., FLACH, K. and SCHIMEL, D.S. 1989 'Texture, climate, and cultivation effects on soil organic matter content in US grassland sites' *Soil Science Society of America Journal* 53, 800-850

CHRISTIAN, J.M. and WILSON, S.D. 1999 'Long-term ecosystem impacts of an introduced grass in the northern Great Plains' *Ecology* 80 (7), 2397-2407

COUPLAND, R.T. 1992 'Mixed prairie', in R.T. Coupland (ed.) *Natural Grasslands, Introduction and Western Hemisphere. Ecosystems of the World.* New York, Elsiver

DAVIDSON, A. 2000 *Integrating Field Sampling and Remotely Sensed Data for Monitoring the Function and Composition of Northern Mixed Grass Prairie* PhD Thesis. University of Toronto, Toronto, 225 pp

EBDON, D. 2000 *Statistics in Geography* (2nd Edition). Malden MS, Blackwell Publishers

ENVIRONMENT CANADA 2000 National Climate Data and Information Archive, available online: <*http://www.climate.weatheroffice.ec.gc.ca/Welcome_e.html*>

GOUDRIAAN, J. 1992 'Biosphere structure, carbon sequestering potential and the ^{14}C carbon record' *Journal of Experimental Botany* 43, 1111-1119

HALL, D.O. and RAO, K.K. 1999 *Photosynthesis* (6th Edition) Sussex UK, Cambridge University Press

HAM, J.M. and KNAPP, A.K. 1998 'Fluxes of CO_2, water vapor, and energy from a prairie ecosystem during the seasonal transition from carbon sink to carbon source' *Agriculture and Forest Meteorology* 89, 1-14

KEPNER, W.G., WATTS, C.J., EDMONDS, C.M., MAINGI, J.K., MARSH, S.E. and LUNA, G. 2000 'A landscape approach for detecting and evaluating change in a semi-arid environment' *Environmental Monitoring and Assessment* 64, 179-195

LLOYD, J. 1999 'The CO_2 dependence of photosynthesis, plant growth responses to elevated CO_2 concentrations and their interaction with soil nutrient status, II. Temperate and boreal forest productivity and the combined effects of increasing CO_2 concentrations and increased nitrogen deposition at a global scale' *Functional Ecology* 13, 439-459

LESICA, P., and DELUCA, T. 1996 'Long-term harmful effects of crested wheat grass on Great Plains grassland ecosystem' *Journal of Soil and Water Conservation* 51, 408-409

LI, Y. and JI, J. 2002 'Framework of a regional impacts assessment model and its application on arid/semi-arid region' available online: <*http://www.iemss.org/iemss2002/proceedings/pdf/ volume%20due/140_li.pdf*>

SASKATCHEWAN SOIL SURVEY 1992 *Grasslands National Park Soil Survey*. Unpublished report. University of Saskatchewan, Saskatoon, Saskatchewan, Canada

STEVENS, J. 1996 *Applied Multivariate Statistics for the Social Sciences* (3rd Edition). Mahwah, NJ, Lawrence Erlbaum Associates Inc.

TAYLOR, J.A. and LLOYD, J. 1992 'Sources and sinks of atmospheric CO_2' *Australian Journal of Botany* 40, 407-418

ZHANG, C., GUO, X., WILMSHURST, J. and SISSONS, R. 2004. 'The evaluation of broadband vegetation indices on monitoring northern mixed grassland' *Prairie Perspectives* (This issue)