2008 Project Abstract
For the Period Ending June 30, 2011

PROJECT TITLE: Climate change, CO_2, and prairie/forest production
PROJECT MANAGER: Peter Reich
AFFILIATION: University of Minnesota
MAILING ADDRESS: 1530 Cleveland Avenue North
CITY/STATE/ZIP: St. Paul, MN 55108
PHONE: 612-624-4270
E-MAIL: preich@umn.edu
WEBSITE: http://forestecology.cfans.umn.edu/index.html
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2008, Chap. 367, Sec. 2, Subd. 3(p)

APPROPRIATION AMOUNT: $330,000

Overall Project Outcome and Results

Funds from ENRTF were used to help establish, maintain, and expand studies regarding impacts of elevated carbon dioxide and changing climate on productivity (i.e. carbon acquisition) and carbon sequestration of woody and herbaceous vegetation. Two new state-of-the-art open air experiments were begun. A new biofuel-oriented experiment was installed in 72 elevated CO2 plots within the ongoing BioCON (Biodiversity, CO2, and Nitrogen) experiment – an effort started in 1997 that is examining how plant communities respond to environmental changes in biodiversity, CO2, and Nitrogen; these plots were planted with potentially “high-yielding” woody and herbaceous perennials. A Boreal Forest Warming experiment in Cloquet and Ely was installed, planted and warming treatments implemented in 2009 and 2010. ENTRF funds were also used to support specific carbon cycling measures in the original, ongoing BioCON experiment. The following findings were documented:

1. In all studies, results showed that acquisition of new carbon is likely in a world with higher CO2 levels and/or with modest warming, but is significantly dampened during periods of low water availability or when soil nutrients are limiting.
2. Long-term sequestration in soil of acquired carbon is likely modest due to the rapid return (through respiration of roots and decomposers) of new carbon to the atmosphere.
3. Soil carbon storage is likely dependent upon soil characteristics however, with sandy soils in our experiments less able to build up carbon stores than finer-textured soils might be.
4. Results suggest considerable potential to grow biomass carbon that could potentially contribute to biofuel offsetting of fossil fuel use and to carbon sequestration in live biomass, dead biomass, and potentially in soils.

Project Results Use and Dissemination

Several publications are in preparation. These include experiment-specific papers (about individual experiments), cross-experiment papers for several related experiments at the Cedar Creek station, and meta-analyses and synthesis papers for which data from this ENRTF project have been combined with similar data from other experiments in North America, Europe, and Asia.

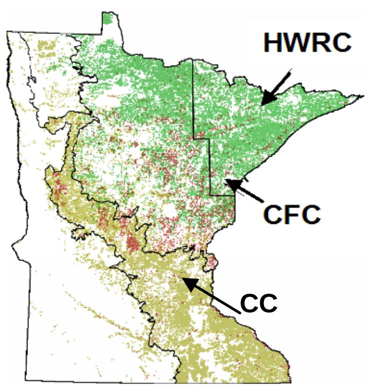
Environment and Natural Resources Trust Fund 2008 Work Program Final Report

Date of Report: August 15, 2011
Final Report
Date of Work program Approval: June 10, 2008
Project Completion Date: June 30, 2011

I. PROJECT TITLE: Climate change, CO2, and prairie/forest production

Project Manager: Peter Reich
Affiliation: University of Minnesota
Mailing Address: 1530 Cleveland Avenue North
City / State / Zip: St. Paul, MN 55108
Telephone Number: 612-624-4270
E-mail Address: preich@umn.edu
FAX Number: 612-625-5212
Web Page address: http://www.forestry.umn.edu/people/facstaff/reich/

Location: Isanti, Carlton, St. Louis counties



HWRC: Hubachek Wilderness Research Center
CFC: Cloquet Forestry Center
CC: Cedar Creek Ecosystem Science Reserve

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$ 330,000**
	Minus Amount Spent:	**$ 333,000**
	Equal Balance:	**$ 0**

Legal Citation: ML 2008, Chap. 367, Sec. 2, Subd. 3(p)

Appropriation Language:
$330,000 is from the trust fund to the Board of Regents of the University of Minnesota to accelerate research simulating future changing CO2, rainfall, and temperature level impacts on biomass production, carbon sequestration, and water quality in prairie and tree species. This appropriation is available until June 30, 2011, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

Amendment approved by LCCMR staff on April 7, 2011.

II. and III. FINAL PROJECT SUMMARY

Overall Project Outcome and Results

Funds from ENRTF were used to help establish, maintain, and expand studies regarding impacts of elevated carbon dioxide and changing climate on productivity (i.e. carbon acquisition) and carbon sequestration of woody and herbaceous vegetation. Two new state-of-the-art open air experiments were begun. A new biofuel-oriented experiment was installed in 72 elevated CO2 plots within the ongoing BioCON (Biodiversity, CO2, and Nitrogen) experiment – an effort started in 1997 that is examining how plant communities respond to environmental changes in biodiversity, CO2, and Nitrogen; these plots were planted with potentially “high-yielding” woody and herbaceous perennials. A Boreal Forest Warming experiment in Cloquet and Ely was installed, planted and warming treatments implemented in 2009 and 2010. ENTRF funds were also used to support specific carbon cycling measures in the original, ongoing BioCON experiment. The following findings were documented:

1. In all studies, results showed that acquisition of new carbon is likely in a world with higher CO2 levels and/or with modest warming, but is significantly dampened during periods of low water availability or when soil nutrients are limiting.
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Several publications are in preparation. These include experiment-specific papers (about individual experiments), cross-experiment papers for several related experiments at the Cedar Creek station, and meta-analyses and synthesis papers for which data from this ENRTF project have been combined with similar data from other experiments in North America, Europe, and Asia.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: On the Ground Field Experiments

Completion of on the ground experiment installation for new 72 plots within the existing BioCON experimental facility at Cedar Creek Ecosystem Science Center (described as Part 1 in the Research Addendum below)*.* Root and soil carbon sampling completed for Parts 1 and 2, which include samples from several experiments

Description: 72 new plots selected, laid out, seeds and plants installed, initial plant measures made. Soil cores and root samples taken for baseline chemical analysis

Summary Budget Information for Result 1: **Trust Fund Budget: $ 40,000**
Revised Budget: $ 38,885
Amount Spent: $ 38,885
Balance: $ 0

Deliverable	Completion Date	Budget	Status
1. Completion of on the ground experiment installation	Dec 2008	$35,708	completed
2. Initial baseline root and soil carbon sampling completed	Dec 2008	$2,082	completed
3. Travel in State to install Warming Experiment	Approved 4-11-2011	$407	Completed
3. Field Equipment repairs to CO2 delivery system	Approved 4-11-2011	$689	Completed

Completion Date: June 2009

Final Report Summary:
Both the potential prairie- and woody-biofuel plots were successfully established. Early mortality was high for the trees though, and these needed to be replanted in 2010. Plants and plots are continuing to be treated experimentally and monitored for biological response after the end date of the LCCMR project.

Result 2: Sampling and Data Set Compilation - Phase 1
2009 treatments applied, and data and samples collected (described in Parts 1 and 2 of Research Addendum). This will maintain experimental treatments in the BioCON experiment, provide information on treatment effects on vegetation growth and composition in the new plots in that experiment, and prepare and archive biomass samples for future chemical analyses.

Description: Plot maintenance, treatments applied, above ground plant growth and composition measured and above ground biomass sampled, weighed and prepared for chemical analysis. Soil CO2 flux measurements taken.

Summary Budget Information for Result 2: **Trust Fund Budget: $ 90,000**
Revised Budget: $ 90,280
Amount Spent: $ 90,280
Balance: $ 0

Deliverable	Completion Date	Budget	Status
1. 2009 year composition**,** biomass and growth data sets compiled	Dec. 2009	$62,200	completed
2. Biomass samples stored and prepped for analysis	March 2010	$8,500	completed
3. CO2 applied to plots	Dec 2009	$ 19,580	completed

Completion Date: March 2010

Final Report Summary:
Results 2 were carried out successfully as described in detail in prior "Results Status" reports. All treatments were applied as planned, and samples collected.

Result 3: Sampling and Data Set Compilation - Phase 2
2010 treatments applied, and data and samples collected (described in Parts 1 and 2 of Research Addendum). This will maintain experimental treatments in the BioCON experiment, provide information on treatment effects on vegetation growth and composition in the new plots in that experiment, and prepare and archive biomass and soil samples for future chemical analyses.

Description: Plot maintenance, treatments applied, above ground plant growth and composition measured and above ground biomass sampled, weighed and prepared for chemical analysis. Roots and soils sampled. Soil CO2 flux measurements taken.

Summary Budget Information for Result 3: **Trust Fund Budget: $ 115,000**
Revised Budget: $ 115,835
Amount Spent: $ 115,835
Balance: $ 0

Please note minor adjustment in budget: April 7th 2011 amendment request approved shifting $835 in salaries from Results 1 to Results 4, however, synthesis and compilation of soils, plant composition, biomass and growth data sets from BioCON and B4WARM required additional effort during this result in preparation for final analysis is Results 4.

Deliverable	Completion Date	Budget	Status
1. 2010 year composition**,** biomass and growth data sets compiled	Dec 2010	$61,235	completed
2. Root and soil carbon sampling	Dec 2010	$25,000	completed
3. All years biomass samples collected & prepped for analysis	March 2011	$ 8,500	completed
4. CO2 applied to plots	Dec 2010	$21,100	CO2 applied, Maintaining equip

Completion Date: March 2011

Final Report Summary:
Results 3 were carried out successfully as described in detail in prior "Results Status" reports. All treatments were applied as planned, and samples collected.

Result 4 Complete Lab Analyses and Data Synthesis
This will provide data on total stocks of carbon in plants and soils

Description: Chemical analysis of all years samples, all data sets synthesized and analyzed for final report. Chemical analyses anticipated to be done in the laboratory of a colleague at the University of Nebraska; total number of samples

Both the woody plants and prairie grasses showed greater production under elevated carbon dioxide. For the prairie plots we see (Figure a.) that aboveground biomass was increased by both nitrogen addition and CO2 enrichment, with biomass 31% greater under high levels of both factors, compared with ambient plots. This is mirrored by data showing similar increases in soil CO2 flux (loss of carbon back to the atmosphere) due to the metabolic activity of plant roots and soil organisms, primarily microbes. These data suggest considerable potential to increase biofuel production in a rising CO2 world, especially if soil amendments are also made.

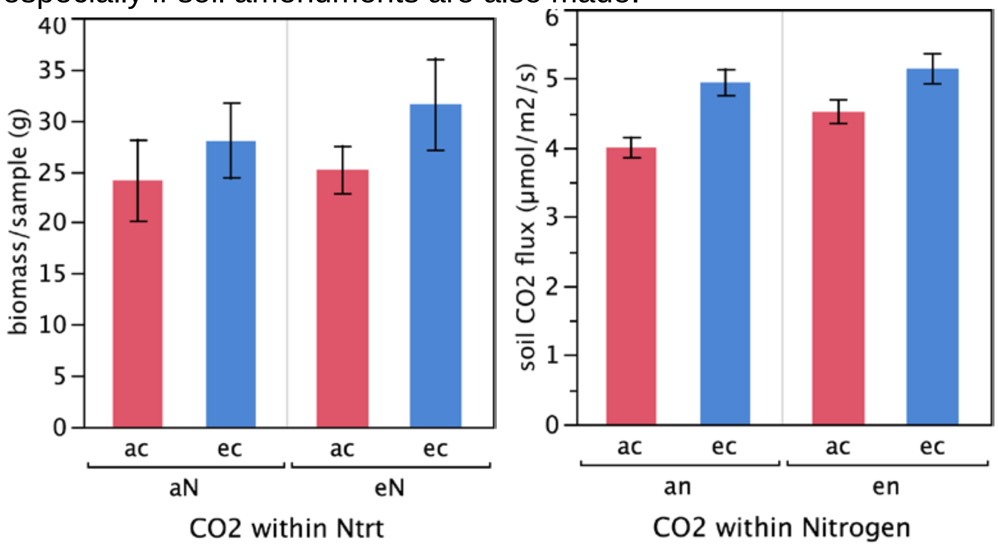

Figure a. Biomass per sample, summer 2010 of the planted prairie biofuel plots at all combinations of ambient nitrogen (aN), enriched nitrogen (eN), ambient CO2 (ac), and elevted CO2 (ec). Biomass was 31% higher at enriched levels of both N and CO2 than ambient control plots, and mean soil carbon dioxide flux was 29% higher at enriched levels of both N and CO2 than ambient control plots.

In the BioCON experiment, we found that the water-savings effects of elevated CO2 (via reduced stomatal conductance) contribute very little to the elevated CO2 stimulation of soil CO2 flux, hence these two can be considered as largely separate. This is consistent with findings that the water-savings effects of elevated CO2 do not ameliorate low rainfall inputs and result in a proportionally larger CO2 effect on biomass under dry conditions. On the contrary, and consistent with multiple-limitation theory, plant biomass was markedly enhanced by elevated [CO2] except when availability of both N and water was low (Figure b.). When examined as individual main effects (averaged across all levels of other treatment factors), higher levels of [CO2], N, and rainfall all increased biomass (by 25%, 14%, and 12%, respectively, the first two significant, $P<0.05$). However, there was a significant three-way interaction between [CO2], water, and N ($P=0.03$, Fig. b). Under higher availability of either water or N, or both, the elevated [CO2] treatment increased biomass by at least 27% (Fig. b). In contrast, under the reduced rainfall and ambient N treatment (Fig. b), biomass was not increased by elevated [CO2]. Thus, our study shows that under sub-optimal levels of two other resources, the potential biomass (i.e. carbon) accumulation in response to elevated [CO2] was negligible, whereas under higher soil resource supply, it was strongly positive. Consequently, our study suggests caution is necessary in extrapolating strong [CO2] fertilization effects in a world with widespread soil nutrient and water limitation. It also suggests that biofuel production will be maximized in a high-CO2 world when other needed plant resources are abundant or made available.

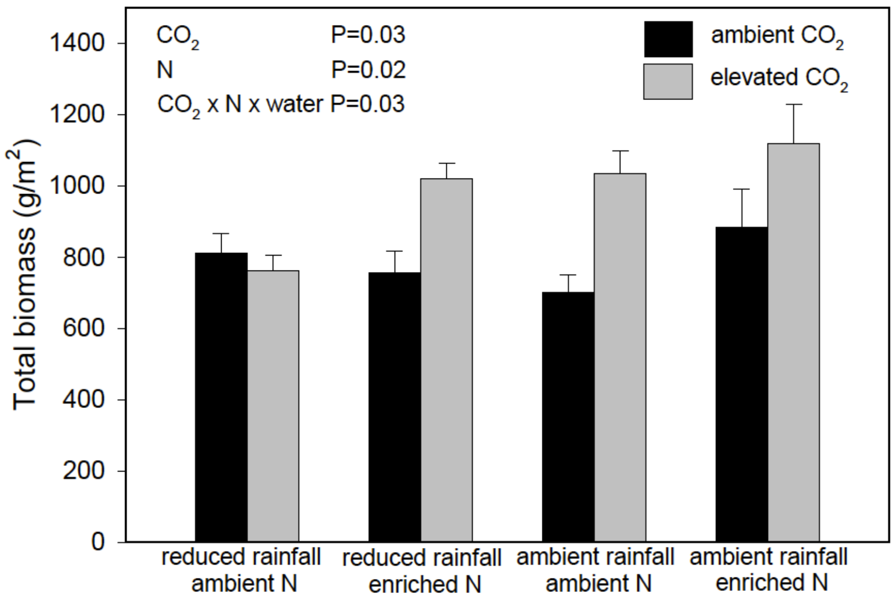

Figure b. Total biomass (aboveground and belowground, 0-20 cm; mean ± one SE of the mean) at all combinations of reduced and ambient rainfall, ambient and enriched N, and ambient and elevated [CO2]. Statistically significant main effects and interactions are shown inset in the figure.

Similar to the results of grassland vegetation, global change (in this case warming) of forest plots, increased carbon uptake but also increased carbon flux back to the atmosphere, commensurately (to the level the data can address this). Also, consistent with results of the BioCON experiment (biomass carbon acquisition data described above), shortfalls of soil moisture limited metabolic carbon flux processes, both belowground (Figure c) and aboveground (figure d). When soil moisture was plentiful, plants in the warmed treatment had

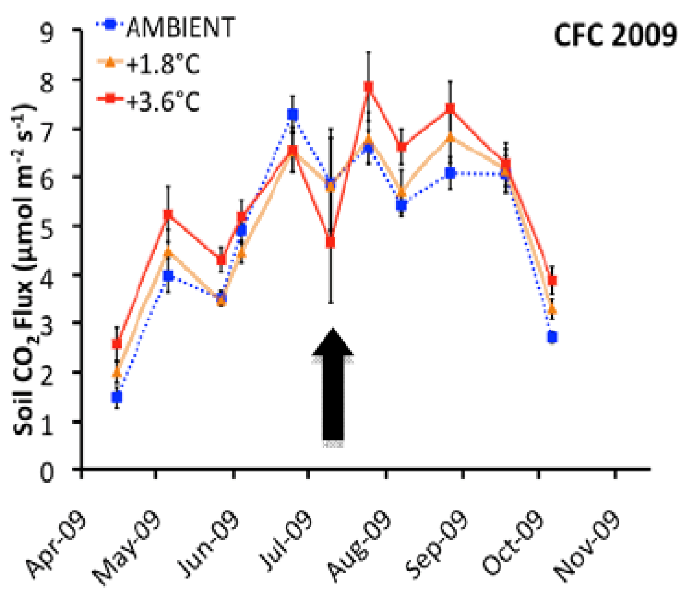

Figure c. Soil CO2 flux measured at Cloquet in 2009. During drought (indicated by arrow), the enhanced CO2 flux in the +3.6 °C treatment was reversed. Similar effects occurred in 2010 (not shown).

heightened photosynthetic carbon gain, but during dry periods, warmer temperatures themselves led to additional soil water loss, which limited photosynthesis considerably (fig d). Similarly, metabolic activity belowground (i.e. roots and soil microbes) and associated carbon flux, was reduced by warming during dry periods when warming exacerbated soil drought (arrow in fig c), but was increased by warming otherwise.

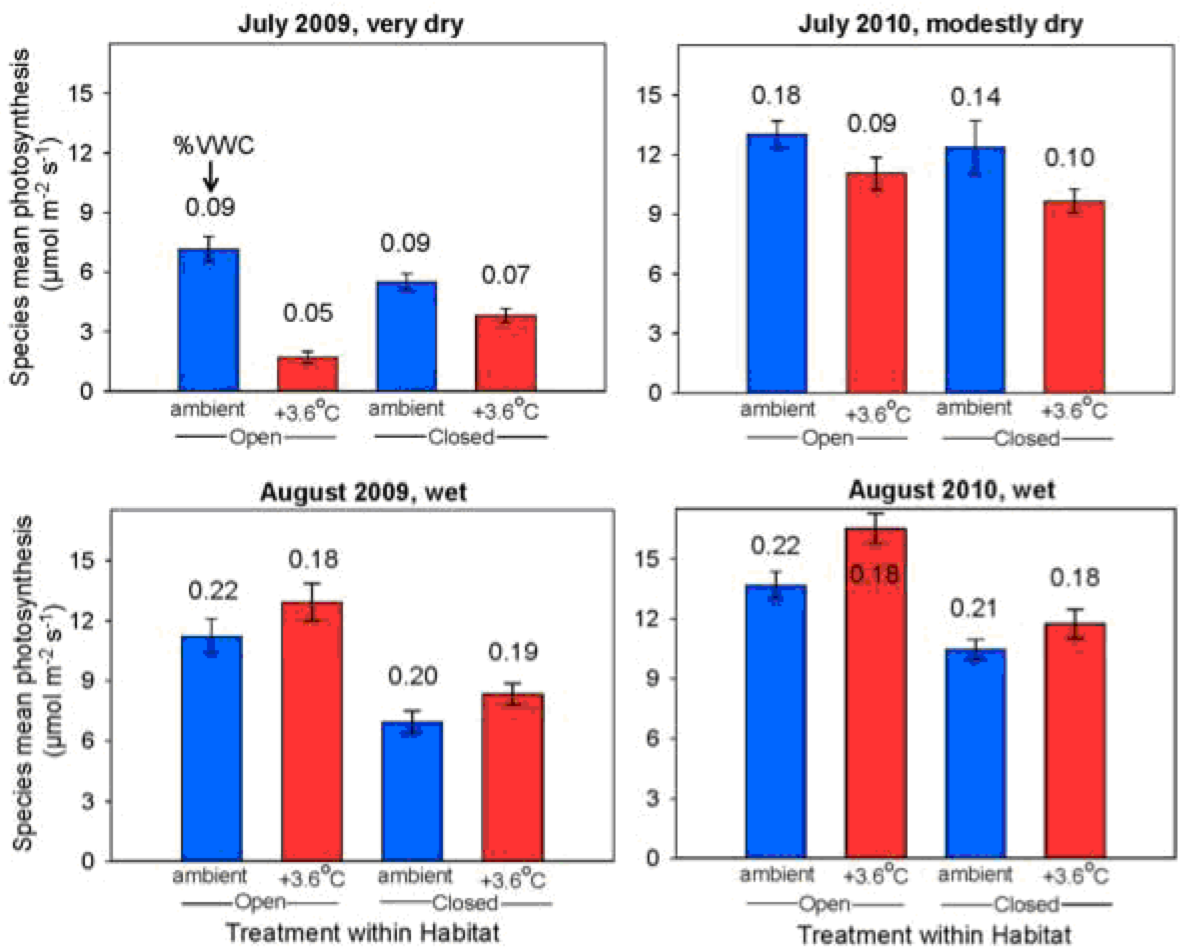

Figure d. An example of how light-saturated photosynthetic carbon acquisition varies with soil moisture (VWC; %volumetric water content). Data are averages for all species measured in each time period at Cloquet. Similar results found in other years at both sites.

Results such as described above emphasize the complexity of plant and ecosystem response to global change factors, and the influence of weather and climate on those responses. The joint impact of rising CO2 and rising temperatures may well lead to increased carbon acquisition in Minnesota grasslands and forests, including those grown for biofuels, but this will be dependent upon whether rainfall amounts or frequency decreases.

V. TOTAL TRUST FUND PROJECT BUDGET: $330,000

Staff or Contract Services: $275,000

This includes $55,000 for undergraduate assistants, $26,000 for professor (partial funding, summers only), $75,000 for postdoctoral research associates, and $119,000 for technicians. All numbers include both salary and fringe benefits

Equipment: 0

Other (CO2, chemical analysis, field supplies, travel): $ 55,000

This includes $23,000 for carbon dioxide, $19,000 for chemical analyses, and $13,000 for miscellaneous supplies and travel.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: John Bradford from the USDA Forest Service (but will not receive any funds from this appropriation), also David Tilman, Clarence Lehman, Rebecca Montgomery, Roy Rich and Jared Trost from the University of Minnesota (but will not receive any funds from this appropriation)

B. Other Funds Proposed to be spent during the Project Period: no technical matching support but there are several externally supported projects with funds that will be spent on related research (approximately $850,000 during the LCCMR project period).

C. Past Spending: no funding from LCCMR, but LCMR/LCCMR funds have supported work (Tilman, Lehman) on related themes at Cedar Creek

D. Time: none

VII. DISSEMINATION: via forest ecology web site, to be published later

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than March 2009, October 2009, March 2010, October 2010 and March 2011. A final work program report and associated products will be submitted between June 30 and August 1, 2011.

IX. RESEARCH PROJECTS:

Research Addendum, May 2008

Project Manager: Peter B. Reich

Climate change and CO2 affect prairie/forest production

Project number: 07-059-000

Submitted by:

Peter Reich

Collaborators

David Tilman
Clarence Lehman
Rebecca Montgomery
Roy Rich
Jared Trost

University of Minnesota

And

John Bradford

U.S. Forest Service, Northern Research Station

I. Abstract

Biofuels will likely be an important part of Minnesota's energy future by providing alternative, renewable energy to lessen our dependence on fossil fuels and simultaneously reduce our carbon emissions. Perennial biofuels can be an important, and perhaps dominant, part of the overall biofuel mix in the state. However, much uncertainty surrounds the growth potential and carbon sequestration potential of different perennial biofuels, especially with respect to anticipated changes in climate and atmospheric chemistry in the present century. The best scientific evidence indicates that by 2040-2060 temperature, rainfall, and atmospheric CO2 levels in Minnesota will differ markedly from those in 1985-2005. These future changes will influence the state's vegetation, including any future biofuel stands. Most relevant to this proposal, future changes in temperature, rainfall and CO2 levels will influence potential biofuel yields, and carbon stored in plants and soils in grassland and woodland communities.

At present, our predictions regarding how grassland and woodland plants will respond to future climate and atmospheric CO2 levels are uncertain and in part educated guesswork, as we have little direct evidence upon which to make such predictions. In this project we leverage several large, complex, field experiments that directly test the impacts of climate and CO2 on grassland and forest species. These experiments use novel approaches that allow manipulative experiments for plants growing in the open in otherwise natural field conditions. For example, to simulate future CO2 levels we experimentally raise CO2 concentrations in the air surrounding the experiments to CO2 levels expected in the future. Simulating future CO2 concentrations is done with vertical pipes that surround clusters of

Climate change, CO_2, and prairie/forest production

At present, the vast majority of biofuel energy in Minnesota and the U.S. is derived from corn-based ethanol. However, several issues could limit the utility and/or expansion of this route to future renewable energy production and reduced greenhouse gas emissions; these point to biofuel from renewable perennials as a possible alternative or complementary strategy. First, although corn ethanol is currently thought to reduce greenhouse gas contributions over its life-cycle by less than 20% compared with motor gasoline (Hill et al. 2006, Wang et al. 2007), even that effect may be illusory, as N_2O flux from fertilized biofuel crops may contribute more to climate warming than any possible saved carbon emissions from fossil fuel displacement (Crutzen et al. 2007). In addition, the land required for corn ethanol production to play a meaningful role would be very large, and would compete with the land needed to raise corn and other foodstocks (Hill et al. 2006). In contrast, greenhouse gas reductions from power produced by biomass (in cogeneration facilities) and/or cellulosic ethanol from perennial plants could be significant, and without competing for quality farmland (Tilman et al. 2006, Groode & Heywood 2007). The technology to produce cellulosic ethanol on a large scale is not currently available, but represents an active area in applied research and development.

Despite the potential for biofuels from perennial plants, many barriers exist and many important questions remain to be answered before their utility can be clearly understood. These include several questions involving growth and carbon storage, the focus of this proposed research. For instance, in addition to contributing to reduced carbon emissions as potentially renewable biofuel, prairie and woody vegetation can also contribute by carbon sequestration potential, in aboveground and belowground biomass, and in soil carbon storage. Research in these areas is still relatively scarce, and given widely disparate results for studies relevant to Minnesota (Fissore, Espeleta, Nater, Hobbie, Reich, and Beduhn; unpublished data), it is difficult at present to be confident regarding which provides the most on-site carbon storage. In addition, how biomass production by grassland and woody species will be influenced by changing environmental conditions is highly uncertain (Norby and Luo 2004, Reich et al. 2006ab), but important, as changes in atmospheric CO2, N, and climate could cause shifts in biomass production as large as 50 to 100% in some cases. In the next several paragraphs, some of these issues relevant to the proposed research are highlighted.

By mid-century, Minnesota and most of the globe is likely to experience higher levels of atmospheric CO2, warmer temperatures, and altered precipitation amounts and timing (IPCC 2007). The first of these changes is virtually certain, as CO2 is destined to rise for 50 years or more, even if we stop increasing our carbon emissions today. The second of these changes (rising temperatures) is considered extremely likely by the IPCC (2007). The third change (altered precipitation regimes) is considered likely, although predictions of whether a specific region will have increased or decreased precipitation remain uncertain. Although the general mechanisms by which CO2, ambient temperature, and precipitation influence grassland and woody vegetation are widely recognized, the realized impact of changes in each of these are highly dependent upon (a) the innate physiology of the individual plant species in question, (b) the characteristics of the plant community, which for instance depend in part on the mix of plant species, and (c) the mix of other environmental factors that can influence responses to CO2, temperature or precipitation. These other factors include possible interactions among the three environmental factors listed above, but in addition, include possible interactions with soil conditions, nutrient supply, or others. The uncertainties are critical to our collective scientific capacity to predict future atmospheric concentrations of greenhouse gases and future climate—uncertainties regarding the CO2 fertilization effect (i.e. enhancement of crop, forest and grassland productivity) and its impact on atmospheric CO2 levels represent a large, if not the single largest, uncertainty in our capacity to predict future global carbon cycling (IPCC 2007).

For good reasons then, currently there are no published estimates of how Minnesota's potential perennial biofuel species will respond to changes in CO2, temperature or precipitation. Although our proposed project cannot hope to fully answer these questions, we believe it will begin to provide important and meaningful information, and do so in an economically efficient way by building our LCCMR project onto expensive ongoing field experiments that manipulate CO2, temperature and precipitation. Such experiments are scarce because they require substantial funding, experimental infrastructure, and long-term planning and programming. As an example of the rarity of these studies we plan to "piggy-back" on, there are only four long-term free-air CO2 experiments that manipulate perennial vegetation in North America, only one of these (ours) has manipulated nitrogen supply as well as CO2, and only one of these (ours) includes a variety of species types and mixtures as part of the experimental design. Our grassland rainfall manipulation and warming studies and our forest warming study are also rare (see description of Part 2 below).

Given that carbon is a necessary plant nutrient, plants should increase growth with rising CO2 levels. In fact, synthetic analyses of all open-air studies show that elevated CO2 generally does increase plant biomass production, with a noted range from -42% to +89% for individual outdoor studies without chambers (Ainsworth and Long 2005) and with average enhancements (from several reviews) of aboveground biomass of grassland and woody plants ranging from +20 to +38% depending on the study (e.g., Curtis and Wang 1998, Wand et al. 1999, Ainsworth and Long 2005). In our BioCON experiment, plots experiencing elevated CO2 coupled with modest nitrogen fertilization have had 40% greater biomass than control plots over a nine-year period (Reich et al. 2006a, Reich, unpublished data). This raises the question of what might be the maximum productivity of specifically constructed communities under elevated CO2, with and without modest nitrogen fertilization.

Given this impressive "fertilization" impact of elevated CO2, the potential for continued enhancement of biomass in agricultural, forestry and natural communities has been long considered by some to be a positive effect overall of rising carbon emissions, and one that potentially can help slow down the rise of CO2 in the atmosphere. However the achieved increase in biomass due to elevated CO2 is not uniformly high and is dependent upon (a) nitrogen availability, with plots under elevated nitrogen supply more responsive to elevated CO2 (Reich et al 2006ab), (b) the species or functional diversity of the plant community, with more diverse plots more responsive to elevated CO2 (Reich et al. 2001a, 2004), and (c) the degree of water limitation, with modestly water limited ecosystems more responsive to elevated CO2 than either wet or dry ones (Reich et al. 2006b). Responses to rising temperatures will also be difficult to predict. Higher temperatures can directly increase growth rates during cooler times of the growing season (and extend the growing season as well) but directly decrease growth rates if hot spells become excessive or prolonged. Additionally, if precipitation is unaltered, higher temperatures alone will lead to greater soil water deficits. Moreover, in aggregate, changes in temperature and soil moisture will alter soil nutrient availability in ways difficult to predict. Thus, responses to warming will vary among sites and species depending on the relative degree of limitation by low vs. high temperature and on the specific precipitation and growing season temperatures of a given year or site. Our proposed project will address the issues raised in this and earlier paragraphs in several ways.

First, we propose to add 72 plots to an existing open-air elevated CO2 project (Part 1). Half of the plots will be used for grassland species and the other half for woody plants. In each case we will select plant materials (see below) designed to maximize biomass production. These plots, in conjunction with our existing mixtures and monocultures, will give us a data set useful in evaluating the relative range of biomass responses to future CO2 levels and how much these can be boosted by modest nitrogen inputs. The new plots will also provide some idea of the maximum productivity we might expect under future CO2 levels from carefully designed perennial systems. Our plots are imperfect for woody plants, which would be better served by larger plots and longer-term CO2 experiments (beyond the financial scope of the LCCMR program). Nonetheless, we believe that some information on responses of very young trees is still much better than having no information whatsoever.

Second, we propose to make specific measurements and analyses in several existing experiments that will provide us with meaningful information relevant to carbon sequestration responses (Part 2). These will be made using expensive experiments established (with non-LCCMR funds) for related, but distinct ecological purposes (see below). The additional measurements we propose to make include assessments of total carbon stocks in roots and in soils to 1-meter depth, as well as measures of the flux of CO2 from the soil to the atmosphere. These measurements will provide an indication of whether root and soil carbon storage is likely to increase, or decrease, and by what magnitude, following experimental warming, precipitation alteration, or elevated CO2. The additional analyses would logically include analyses of the new data, but would also include analyses focused on implications of the experimental data from the existing experiments from an energy (i.e., biofuel) perspective.

Hypotheses

Hypothesis 1 (relevant to Part 1). Fast-growing woody plants will have the largest biomass and carbon storage, followed in rank order by our "designed prairie mixtures" and by our existing randomly assembled prairie mixtures and monocultures. The woody plants will additionally have the largest responses to elevated CO2 and nitrogen availability, in all combinations. Response to elevated CO2 will depend upon level of nitrogen availability as well (with greater response to CO2 predicted with modest nitrogen fertilization than without). These hypothesized responses, if supported by the evidence, would indicate a good potential for perennial prairie mixes or woody plants to sustainably produce high biomass under future conditions with modest or no inputs.

Hypothesis 2 (relevant to Part 2). We hypothesize that treatments that limit root and soil microbial activity will enhance root and soil carbon storage and conversely those that enhance root and soil microbial activity will reduce roots and soil carbon storage. This hypothesis is uncertain and is offered as a working hypothesis, rather than a prediction. The rationale for this hypothesis is that the balance between changes in new carbon inputs (biomass production) and carbon losses (via plant respiration and decomposition processes) will be the main driver of whether a given stand is a sink or source of carbon belowground. Moreover, this hypothesis is based on the notion that belowground processes largely determine belowground carbon storage—witness high amounts of carbon belowground in systems with slow decomposition rates (peatlands, Great Plains grasslands). Thus, we hypothesize that warming will stimulate root and soil microbial activity (except during drought) and increase carbon losses; whereas precipitation removal will suppress root and soil microbial activity (due to dry soils) and enhance belowground carbon storage; and elevated CO2 will have complex effects by dint of changes in the chemistry and amount of carbon allocated belowground (Adair et al, submitted).

III. Description of methodology

Our approach is explicitly "value-added" by "piggy-backing" the planned studies on existing projects. Part 1 involves a set of new plots in a single experiment and a variety of related activities. Part 2 involves a set of belowground measurements in a variety of plots (including those in Part 1) and analyses focused on implications of the experimental data from the existing experiments from an energy (i.e., biofuel) perspective.

Part 1. 72 New plots: potential biofuels under elevated carbon dioxide.

The Biodiversity x CO2 x Nitrogen (BioCON) Experiment. For the new plots in Part 1, we will use the BioCON experiment at the University of Minnesota's Cedar Creek Long-Term Ecological Research site. *CO2*. Six circular areas (24 m dia.) were randomly assigned, three each to ambient and elevated CO2 (560 ppm, early spring to late fall), which is delivered using free-air CO2 enrichment (FACE) technology (Hendrey *et al*. 1993). Within the central 20 m diameter-zone in each ring, we established 61-63 square (2m x 2m) plots, totaling 371 in all, which are used in a set of complementary ongoing CO2 x nitrogen x richness or composition experiments (e.g., Craine et al. 2001ab, 2004; Reich et al. 2001ab, 2004, 2006; Dijkstra et al. 2005, 2007; Chung et al. 2007).

There are also an additional 72 plots (1.5 x 2 m), 12 per ring, that were used in a complementary study of CO2 effects on oak establishment in secondary successional grasslands (Davis et al. 2007). The new plots to be established in Part 1 of this project will be located in those same 72 plots, as the prior experiment has been completed. The new experiment will be a 2 x 2 x 2 factorial with nine replicates, consisting of two vegetation types (woody vs. grassland), two levels of CO2 and two levels of nitrogen fertilization (none and +4 g N m^{-2} yr^{-1} ammonium nitrate (NH_4NO_3). The nitrogen fertilizer will be delivered in equal fractions in early May, June and July, with a ^{15}N label that gives the nitrogen a unique positive signature. We note that N treatments in BioCON are relevant to questions regarding response to CO2 across soils/sites differing in soil nitrogen supply as well as to potential interactions of CO2 with nitrogen deposition, which varies globally from much less to as much as our nitrogen addition treatment.

The grassland plots will employ mixtures of six species mixtures and include two species each from the following three functional groups: C4 grass, C3 grass, and nitrogen-fixing legume. The species will be switchgrass (*Panicum virgatum*), big bluestem (*Andropogon gerardii*), smooth brome (*Bromus inermis*), quackgrass (*Agropyron smithii*), lupine (*Lupinus perennis*) and roundhead lespedeza (*Lespedeza capitata*). These species are all native or naturalized and have grown well in mixtures in prior biodiversity experiments at the Cedar Creek site (e.g., Tilman et al 1997, Reich et al. 2001ab). The grassland mixture includes a set of species that are likely to have positive interactions (facilitation leading to over-yielding) based on prior experiments with prairie species mixtures (e.g., Tilman et al 2001, 2006ab, Hille RisLambers et al 2003, Reich et al. 2001a, 2004). The species choice will be revisited just before planting, making use of any more recent information.

Three woody taxa will be used in the tree plots; we will focus on fast-growing species known to have high potential to gain and sequester carbon in the short-term in conditions relevant to Minnesota (Fissore, Espeleta, Nater, Hobbie, Reich, and Beduhn; unpublished data). The candidates are hybrid aspen, hybrid poplar, and native cottonwood, based on recommendations from leading researchers in fast-growing short-rotation woody species in Minnesota (e.g., D. Riemenschneider, US Forest Service; W. Berguson, NRRI; A. David, U of Minnesota). We will consult with the investigators of those projects regarding the final choice. A willow taxon may be used instead of one of the candidates, but information at present is insufficient to ensure good growth at our study site. Each woody species plot will include equal numbers of all three taxa grown at a narrow spacing (• • • • • • • • • •• • • • • • • • ••• • • • • • •• • • • •• •

experience growing hybrid poplars in high density field settings in global environmental change experiments (e.g., Reich et al 1984).

Plots will be seeded with the prairie species whereas seedlings of the woody species will be planted. If other (non-LCCMR) funds become available to purchase seeds and plants, we will plant the plots in spring of 2008, before the start of the LCCMR project, in order to gain an additional field season. All other experimental treatments, plot maintenance, and standard measurements will be as made in BioCON in previous years (Reich et al 2001ab, 2006ab). Among other reasons, this allows us to use very well developed protocols and methods, and additionally will enable us to compare the new plots with measurements in the existing plots. Although the new plots will be in their first, second and third year roughly a decade after the existing plots, we will be able to compare the new-plot performance to the existing plots both in the same chronological year (e.g., 2009) as well as the same stage of stand development (e.g., year 3, being 2010 for new plots and 2000 for existing plots). These comparisons are problematic for this reason and will be considered with great circumspection. However, the more important findings will be the comparisons of the new plots considered as a single experiment.

Plots will receive elevated CO2 in all daylight hours from early spring to late autumn each year (Reich et al. 2006). Non-destructive measures of plant height, diameter and leaf area will be made annually for the woody plants. For the prairie mixtures, aboveground plant biomass, abundance, richness, and %cover will be once per year (August) using established methods (Reich *et al.* 2001ab).

Challenges: A major concern involves the short time frame of the LCCMR supported project when viewed against the time frame needed to obtain the best possible information relevant to biomass production, especially for woody plants. All research on woody plants in a field context faces challenges because of both the spatial and temporal scales involved. We recognize this concern, but note that learning a limited amount about influences of environmental change factors such as elevated carbon dioxide on early growth of woody plants being considered for potential biomass and biofuel purposes is still much better than knowing nothing about such responses. It is also important to note that work with fast-growing woody plants represents only a portion of the planned research and that the likelihood of having sufficient time to obtain satisfactory information about perennial grassland species is high: we plan for three years of research (two growing species likely because of the July 1 start date) and have a relatively high degree of confidence that we could continue the grassland plots for at least another year or two from funding to be found in the future—a total of 3 or 4 years is usually sufficient for grassland plots to demonstrate biomass productivity results. In summary, over the 2008-2011 time frame, our research will not as completely answer important questions regarding (especially) woody biomass production in light of global change as well as we would like, but will provide some important information about the physiological responses of woody plants that is critical to developing understanding of the potential productivity responses to various global change factors.

Part 2. Carbon sequestration responses in global change experiments.

We will measure root and soil C, and soil CO2 flux from plots in at least two and as many as five different experiments, all led by Reich (4) or Tilman (1). We will also perform analyses focused on implications of the experimental data from the existing experiments from an energy (i.e., biofuel) perspective. Funds for these detailed measures and analyses are not available in the existing awards supporting those projects, but will be supported by the LCCMR award. The experiments are as follows:

1. New CO2 -Biofuels Experiment. 72 plots, called Part 1 above; part of the BioCON project.
2. Biodiversity- CO2 -N experiment. 323 plots in the existing BioCON experiment; these include all combinations of species richness (1, 4, 9 or 16 species per plot), ambient and elevated CO2, and ambient and enriched nitrogen. Begun in 1998.
3. CO2 -N-water manipulation experiment. 48 plots in the existing BioCON experiment. This experiment examines whether responses to elevated CO2 depend on water supply and nitrogen availability; this includes all combinations of two levels each of water availability x CO2 x N, all in 9-species mixture plots in BioCON. Begun in spring 2007.
4. Biodiversity-climate warming experiment. 40 plots in a warming experiment, part of a grassland biodiversity experiment begun in 1996; the treatments to be used would be the ambient and warmest treatment, and five levels of species richness (1, 2, 4, 8, 16); warming experiment to begin spring 2008.
5. Boreal forest warming experiment. 96 plots in a pair of boreal forest warming experiments at Cloquet Forestry Center and the Hubachek Wilderness Research Center, near Ely. This experiment includes two sites (Cloquet, Ely), three levels of warming (ambient, +2C, +4C), and two habitat types (forest understory, clearing); experiment to begin in 2008.

Experiments 1 and 5 will require “initial” sampling of root and soil carbon prior to (or early in) the experiments; the others all have been sampled before and/or during the experiment. We will sample each plot (by either diagnostic or regularly spaced horizons) to 1-meter depth (if possible) for root and soil carbon in the last year of the LCCMR project, hopefully after three years (Experiments 1, 4, 5), four years (Experiment 3) or 13 years (Experiment 2) of treatments. After 10 years of experience in the BioCON project, we have well developed protocols for coring for roots and soils; for handling, processing, and preparing samples; for chemical analyses; and for data storage and management.

We (and/or collaborators) will also measure soil CO2 flux in selected plots of at least two of the experiments. These measures are made using portable infra-red gas analyzers and chambers (e.g., Craine et al. 2001ab). The available funding from LCCMR is sufficient for only sporadic soil CO2 flux sampling. Unless these can be increased by further funds being sought, they will be considered as qualitative indicators of soil processes, rather than used to assess total carbon budgets of plots. Except at the Ely sites (which are too stony), volumetric moisture will be measured using TDR periodically during the growing season in selected plots at each site. If resources allow, we will use the BROOK90 (or an alternative) model to estimate drainage and evapotranspiration. BROOK90 works well at assessing SWC from 0 to 120 cm depth in Cedar Creek grasslands (Dijkstra *et al.* 2006).

Analyses of data (including data going back as far as 1998) from the existing experiments will be assessed from a biofuels potential perspective. This will include analyses of response of C uptake (i.e. production) and storage in plants and soils in relation to treatments and of implications from both ecological and energy standpoints if biomass were removed for electric power generation or liquid biofuel production.

IV. Description of the results and/or products (deliverables) to be produced from the proposed research

The deliverables of the project will be (1) “on the ground” field experiments that serve the current objectives but which additionally may be valuable resources for continued research; documentation of experimental treatments, including timing and dosage or level (when appropriate); (2) datasets that enable evaluation of biomass and soil carbon responses of grassland and woody vegetation to a variety of environmental changes that will occur in the next century; (3) analyses of those datasets that will highlight the promise, in terms of potential biomass production, of differing “biofeedstocks” and of several measures relevant to soil carbon sequestration, (4) recommendations regarding plant types and management options that would maximize biomass production and soil carbon storage under future environmental conditions, and (5) policy-maker and public education accomplished via a combination of conferencing, reports, seminars, web-based information, and educational materials at the field sites.

V. Timetable for completing the proposed research (milestones and dates)

Part 1. New experiment establishment and related aboveground measures.

Date	Milestone
1 July-08	Project begins
31 Dec-08	72 new plots selected, laid out, seeds and plants ordered
1 April-09	Plots planted; treatments begun[1]
30 Aug-09	2009 aboveground plant growth and composition measured
1 April-10	2009 aboveground biomass weighed, prepped for chemical analysis
30 Aug-10	2010 aboveground plant growth and composition measured
15 Mar-11	2010 aboveground biomass weighed, prepped for chemical analysis
30 Jun-11	Data synthesis complete, final report complete, project end

[1]If additional non-LCCMR funds are available; the new plots will be planted in late spring 2008, in order to have an additional year of field results before the 30 June 2011 end date.

Part 2. Belowground measures in new Experiment (Part 1) and four other existing experiments. Experimental treatments in all five experiments will be ongoing, and thus are not shown on the milestone table.

Date	Milestone
1 July-08	Project begins
1 Nov- 08	Initial root and soil carbon sampling completed
30 Aug -09	2009 soil CO2 flux measurements;
30 Aug-10	2010 soil CO2 flux measurements completed;
15 Oct-10	Roots and soils sampled to 1-meter depth (as possible)
15 Mar-11	Chemical analyses of roots and soils complete
30 June-11	Data synthesis complete, final report complete, project end

VI. Deliverable products correlated to the timetable and budget

The deliverables of the project and their relationship and the timetable and budget:

Climate change, CO_2, and prairie/forest production

(1) "on the ground" field experiments; and documentation of experimental treatments: as the experiments are ongoing in time and require roughly constant staff input per year, these deliverables will be a constant product and require roughly one-fourth of staff time. All CO2 costs are dedicated to this deliverable.
(2) datasets that enable evaluation of responses of grassland and woody vegetation to coming environmental changes: compiling these datasets will require roughly one-third to one-half of all staff time and all remaining supplies and analyses costs. These costs will be incurred in close proportion to the timing of annual measurements of soil CO2 flux, and root and soil carbon. As root and soil carbon sampling will largely be in the final year, the costs for all of the deliverables in this category will be higher in that year.
(3) analyses:

Bradford) will spend time on projects (not paid for by LCCMR) closely related to and complementary to this current project. Additionally, five grants currently in place (two U.S. National Science Foundation [NSF], two U.S. Department of Energy [DOE], and one U.S.D.A. Forest Service) provide • • • • • ‰• • • • ••• •• • • • • • • •• •••• • • • • • • • • •••• • including the experimental facilities, maintenance of plots and treatments, data management, and many other measures of plant physiological, growth, plant-pest interactions, biogeochemistry, and others that are beyond the scope of the LCCMR project but provide complementary data.

Note on budget: Bahauddin, Trost, and Worm are all technical support staff; and currently are and will be supported for the remainder of their appointments by other grant funds to the investigators; i.e., the requested funds here will support part of their work tasks and appointment.

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VIII. Identification and background of principal investigators and cooperators who will carry out the proposed research

Biographical sketch- Peter B. Reich

Department of Forest Resources
1530 Cleveland Avenue North, University of Minnesota, St. Paul, MN 55108
Phone: 612-624-4270; FAX 612-625-5212; E-mail preich@umn.edu

Education
Ph.D. (1983) Environmental Biology and Plant Ecology, Cornell University, Ithaca, NY
M.S. (1977) Forest Ecology, University of Missouri, Columbia, MO
B.A. (1974) Writing and Physics, Goddard College, Plainfield, VT

Professional Experience
Regent Professor, University of Minnesota, St. Paul, MN, 2007 -
Distinguished McKnight University Professor, 2003-
F.B. Hubachek, Sr., Professor, Dept Forest Resources, U. Minnesota, St. Paul, MN, 1991-
Assistant /Associate Professor, Dept Forestry, U. Wisconsin, Madison, WI, 1985-1991.

5 publications relevant to this project:
Dijkstra, F.A., J.B. West, S.E. Hobbie, P.B. Reich. 2007. Dissolved inorganic and organic N leaching from a grassland field experiment: interactive effects of plant species richness, atmospheric [CO2] and N fertilization. Ecology 88:490–500.
Reich, P.B., J. Knops, D. Tilman, , J. Craine, D. Ellsworth, M. Tjoelker, T. Lee, S. Naeem, D. Wedin, D. Bahauddin, G. Hendrey, S Jose. K. Wrage, J Goth, W. Bengston. 2001. Plant diversity enhances ecosystem responses to elevated CO2and nitrogen deposition. Nature 410:809-812.
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Tilman D, PB Reich & JMH Knops. 2006. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441:629-632.

5 other peer-reviewed publications (out of >280 in total)
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Climate change, CO_2, and prairie/forest production

Synergistic Activities, Honors, Recognition, and Service (selected recent)

Institute for Scientific Information (ISI) Science Citation Index, List of Top 20 Ecologists and Environmental Scientists in the World, 2002 – present (Current rank #6)

National Institute on Climate Change Research, Midwestern Regional Panel, 2006-07

National Science Foundation, Biocomplexity and the Environment Program, Coupled Biogeochemical Cycles Panel member, 2004

NSF, Ecological and Evolutionary Physiology Panel Member, 1994-97

Editorial Review Board (or equivalent): *Oecologia (2006-08), Tree Physiol*, *(1993-95, 2004-) Trees (1991-97), Can Journal Forest Research (1992-98), Ecologyy/Ecological Monographs (1995-99)*

BIOGRAPHICAL SKETCH - G. David Tilman

BIRTH: Aurora, Illinois

ADDRESS: Department of Ecology, Evolution and Behavior
100 Ecology Building, 1987 Upper Buford Circle,
University of Minnesota, St. Paul, Minnesota 55108-6097

EDUCATIONAL HISTORY:
University of Michigan 8/67-5/71 B.S. Zoology (High Distinction)
University of Michigan 9/71-4/76 Ph.D. Zoology (Ecology)

PROFESSIONAL APPOINTMENTS:
Assistant Professor, University of Minnesota 1976-1980
Associate Professor, University of Minnesota 1980-1984
Professor, University of Minnesota 1984-1996
Director, Cedar Creek Natural History Area 1992-present
Distinguished McKnight University Professor 1996-2001
Member, Institute for Advanced Study, Princeton, NJ 2000
Regents Professor, University of Minnesota 2002-present

AWARDS, HONORS, NATIONAL AND INTERNATIONAL SERVICE (selected):
Guggenheim Fellow 1984-1985
Fellow, American Association for the Advancement of Science 1985
W. S. Cooper Award, Ecological Society of America 1989
Elected to the American Academy of Arts and Science 1995
Pew Scholar in Conservation Biology 1995-1998
MacArthur Award, Ecological Society of America 1997
Designated the Most Highly Cited Environmental Scientist of the Decade (1990-2000) by Essential Science Indicators 2000
Elected to the National Academy of Sciences 2002
Named Lectures and Keynote Addresses, including:
50th Anniversary of the Ecological Society of Japan 2003
The Holm-Thomas Lecture at Stanford University 2001
The Henry Oosting Lecture at Duke University 1999
Glaser Distinguished Lecturer, Florida International University 1999
Keynote Address, IX Congress on the Italian Society of Ecology 1999
The Moore Lecture, University of Virginia 1991
The Per Brink Lecture, Lund University, Sweden. 1988

SELECTED PUBLICATIONS:
Fargione, J., C. S. Brown and D. Tilman. 2003. Community assembly and invasion: An experimental test of neutral versus niche processes. Proceedings of the National Academy of Sciences 100:8916-8920.
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BIOGRAPHICAL SKETCH

Clarence L. Lehman
Adjunct Professor, Department of Ecology, Evolution, and Behavior

University of Minnesota

100 Ecology Building, 1987 Upper Buford Circle, St. Paul, Minnesota 55108-6097
Email lehman@umn.edu; Phone 612-625-5434; Fax 612-624-6777

Education and Training

Ph.D., Ecology, University of Minnesota, 2000
M.S., Ecology, University of Minnesota, 1991

Relevant Professional Experience

Adjunct Professor, Department of Ecology, Evoultion, and Behavior, University of Minnesota, 2000-present. Research and teaching on theoretical ecology, bioenergy, climate change, and computer applications to biology.

Associate Director, Cedar Creek Natural History Area, 1999-2006. Oversight, operations, and future planning for the field site.

Relevant Publications

Tilman, D.; Hill, J; Lehman, C. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* 314:1598-1600. *[Introduces native grass/forb mixtures as a potential carbon-negative feedstock.]*
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Tilman, D.; Lehman, C. L.; Thomson, K. T. 1997. Plant diversity and ecosystem productivity: Theoretical considerations. *Proc. Natl. Acad. Sci. 94:1857-1861.*

Tilman, D.; May, R. M.; Lehman, C. L.; Nowak, M. A. 1994. Habitat destruction and the extinction debt. *Nature 371:65-66.* (Highlighted in The New York Times 27 September 1994, Science 26 August 1994, and other media.)

Synergistic Activities

Public engagement: Public lectures (over 30 in the past year) explaining bioenergy and its relationship to the environment, with public groups ranging from secondary schools to local environmental meetings to large public gatherings. The most prominent public gathering was on the west lawn of the U.S. Capitol in Washington DC (March 2007), addressing a group that the Washington press described as the largest gathering on climate yet assembled.

Prairie restoration: Personal experience (20 years) restoring degraded farmland to native prairie flora, accompanied by experiments for adaptive management of the restored prairie areas. The experiments test optimal and economic establishment methods and optimal seasons for seeding. This practical experience now can be applied to biofuel plantations.

Restoration aids: PRESTO, interactive computer software for prairie restoration. Selects native grasses and forbs suitable for a specified geographic area under specified soil, sun, and moisture conditions. Techniques and software here will be relevant to future restorations for biofuel plantations.

Research tools: DECLARE, a software system for field data entry on hand-held and laptop computers, and other scientific software (in http://www.cedarcreek.umn.edu/tools/). Relevant to data gathering for bioenergy research, as well as other purposes.

Data base support: PERM1, a technique for very long term storage of archival data (in http://www.cedarcreek.umn.edu/tools/). Relevant to data stored for future comparison and analysis in long-term projects in government and academia, including current bioenergy endeavors.

BIOGRAPHICAL SKETCH - Rebecca A. Montgomery

Department of Forest Resources
University of Minnesota
1530 Cleveland Avenue North
St. Paul, MN 55108
(612) 624-7249
rebeccam@umn.edu

Education and Training

Occidental College (California), Biology, A. B. Magna cum laude, 1994
University of Connecticut, Ecology and Evolutionary Biology, Ph.D., 1999
University of Wisconsin-Madison, Botany, post-doc, 2000-2003

Research and Professional Experience

2004-present	Assistant Professor, Forest Resources, University of Minnesota
2003-2004	Research Associate, Forest Resources, University of Minnesota
2003-2004	Instructor, Forest Resources, University of Minnesota
2000-2003	Research Associate, Botany, University of Wisconsin

Ten Publications

Dickie, I. A., **R. A. Montgomery**, P. B. Reich and S. A. Schnitzer. 2006. Physiological and phenological responses of oak seedlings to oak forest soil in the absence of trees. *Tree Physiology* 27: 133-140.

Montgomery, R. A. 2004. Effects of understory vegetation on patterns of light attenuation near the forest floor. *Biotropica* 36: 33-39.

Harms, K. E., J. S. Powers, **R. A. Montgomery.** 2004. Variation in small sapling density, understory cover and resource availability in four Neotropical forests. *Biotropica* 36: 40-51.

Givnish T.J., **R.A. Montgomery** and G. Goldstein. 2004. Adaptive radiation of photosynthetic physiology in the Hawaiian lobeliads: light regimes, static light responses, and whole-plant compensation points. *American Journal of Botany* 91: 228-246.

Montgomery, R. A. 2004. Relative importance of photosynthetic physiology and biomass allocation for tree seedling growth across a broad light gradient *Tree Physiology* 24:155–167.

Nicotra, A. B., R. L. Chazdon & **R. A. Montgomery***.* 2003. Sexes show contrasting patterns of leaf and crown carbon gain in a dioecious rainforest shrub. *American Journal of Botany* 90:347-355.

Cabin, R. J., S. G. Weller, D. H. Lorence, S. Cordell, L. J. Hadway, **R. Montgomery**, D. Goo, and A. Urakami. 2002. Effects of light availability, alien grass, and native species additions on Hawaiian dry forest restoration. *Ecological Applications* 12:1595-1610.

Montgomery, R. A. and R. L. Chazdon. 2002. Light gradient partitioning by tropical tree seedlings in the absence of canopy gaps. *Oecologia* 131:165-174.

Montgomery, R. A. and R. L. Chazdon. 2001. Forest structure, canopy architecture and light transmittance in old-growth and second-growth stands of lowland rainforest in NE Costa Rica. *Ecology* 82: 2707-2718.

Chazdon, R. L., and **R. A. Montgomery**. 2001. La adquisición de carbono en las plantas. In: M. R. Guariguata and G. H. Kattan (Eds.) *Ecología y Conservación de Bosques Neotropicales.* Editorial Libro Universitario Regional, Costa Rica

Climate change, CO_2, and prairie/forest production

Synergistic Activities

I am currently developing a database of plant functional traits for the entire Hawaiian flora in collaboration with Lawren Sack (U Hawaii at Manoa), Becky Ostertag (U Hawaii at Hilo), Jon Price (USGS) and Susan Corderl (USDA Forest Service).

Over the past five years, I have been involved in an international collaboration (>15 countries) examining the controls of leaf decomposition rates in tropical forests around the globe. This project is coordinated by Dr. Jennifer Powers (U Minnesota)

I am a collaborator on a recently funded Research Coordination Network on plant traits (Trait Net) led by Shahid Naeem and Daniel Bunker (Columbia University).

I am working with the MN Department of Natural Resources on the role of changed climate in timing of phenological events in white spruce common gardens originated from across latitudinal and longitudinal gradients.

JOHN BRADFORD

Research Ecologist – USDA Forest Service

Northern Research Station
1831 Hwy 169 E.
Grand Rapids, MN 55744

Voice: (218) 326-7105
Fax: (218) 326-7123
jbbradford@fs.fed.us

EDUCATION

Degree	School	Dates
Ph.D. - Ecology	Colorado State University Fort Collins, CO 80523	Fall 1998 - Spring 2004
B.A. - Biology	Cornell University Ithaca, NY 14853	Fall 1994 - Spring 1996

EXPERIENCE

Title	Employer	Dates
Research Ecologist	USFS Northern Research Station Grand Rapids, MN	July 2006 - Present
Research Ecologist (Postdoc)	USFS Rocky Mountain Research Station Fort Collins, CO 80524	May 2004 - July 2006
Research Associate and Graduate Student	Graduate Degree Program in Ecology Colorado State University Fort Collins, CO	August 1998 - May 2004
Research Associate	Natural Resources Ecology Laboratory Fort Collins, CO	January 2002 - May 2004
Research Associate	Shortgrass Steppe Long Term Ecological Research Site Fort Collins, CO	January 2002 - May 2004

AWARDS

NASA Earth System Science Graduate Student Fellowship	2002 –2004
CSU College of Natural Resources Graduate Scholarships	2002 –2003
National Science Foundation Graduate Student Fellowship	1999 –2002
CSU College of Natural Resources Graduate Scholarships	1999 –2000
CSU College of Natural Resources Tuition Scholarship	1998 –1999
"Caring for the Land" Award for integrity/performance from the U.S.F.S.	1993

PROFESSIONAL SERVICE

Member: Ecological Society of America, American Geophysical Union, International Association for Landscape Ecology

Climate change, CO_2, and prairie/forest production

Ad-hoc Reviewer: Ecological Applications, Ecology, Ecosystems, Global Change Biology, Biogeochemistry, Global Ecology and Biogeography, Oecologia, Nature, Diversity and Distributions, Remote Sensing of Environment, Forest Ecology and Management

SELECTED PUBLICATIONS

Bradford, J.B., Birdsey, R. A., Joyce, L. A., and M. G. Ryan. (In review) Tree age, disturbance history, and carbon stocks and fluxes in subalpine Rocky Mountain forests. *Global Change Biology.*

Sherrill, K. R., Lefsky, M.A., **Bradford, J.B**., and M.G. Ryan. (In review) Forest Structure Estimation and Pattern Exploration from Discrete Return Lidar in Subalpine Forests of the Central Rockies. *Canadian Journal of Forest Research.*

Bradford, J.B. and M.G.Ryan. (In review). Approaches to quantifying soil respiration at landscape scales. Book Chapter.

Bradford, J. B., Hollinger, D. Y., Kolka, R. K., Weishampel, P., Smith, M. L, Ryan, M.G., and R. A. Birdsey. (In review). Landscape Carbon Sampling Strategy – Lessons Learned. Book Chapter.

Bradford, J.B. and N. T. Hobbs. (2008) Analysis of options for elk population management in Rocky Mountain National Park. *Journal of Environmental Management.* 86:520-528*.*

Binkley, D., Kashian, D. M., Boyden, S., Kaye, M. W., **Bradford, J. B**., Arthur, M. A., Fornwalt, P. J., and M. G. Ryan. (2006) Patterns of Growth Dominance in Forests of the Rocky Mountains, USA. *Forest Ecology and Management* 236: 193-201.

Bradford, J.B. Lauenroth, W.K., Burke, I.C. and J.M. Paruelo. (2006) The influence of climate, soils, weather and land-use on primary production and biomass seasonality in the U.S. Great Plains. *Ecosystems* 9: 934-950.

Bradford, J.B. and W. K. Lauenroth. (2006) Controls over cheatgrass invasion: the importance of climate, soils, disturbance and seed availability. *Journal of Vegetation Science 17: 693-704.*

Lauenroth, W.K. and **J.B. Bradford**. (2006) Ecohydrology and the Partitioning of AET between transpiration and evaporation in a semiarid steppe. *Ecosystems* 9: 956-967.

Bradford, J.B., Lauenroth, W.K., and I.C. Burke. (2005) The impact of cropping on net primary production in the U.S. Great Plains. *Ecology* 86(7) 1863-1872.

Bradford, J.B., Hicke, J., and W. K. Lauenroth. (2005) The relative importance of light-use efficiency modifications from environmental conditions and cultivation for estimation of large-scale net primary productivity. *Remote Sensing of Environment* 96(2) 246-255.

Adler, P.B. and **J.B. Bradford** (2002) Compensation: an alternative method for analyzing diversity-productivity experiments. *Oikos* 96: 411-420.

Climate change, CO_2, and prairie/forest production

Climate change, CO_2, and prairie/forest production

Attachment A: Final Budget Detail for 2008 Project

Project Title: Climate change, CO_2, and prairie/forest production

Project Manager Name: Peter Reich

Trust Fund Appropriation: $330,000

2008 Trust Fund Budget	**Revised Results 1 Budget:** Revised as of April 7, 2011	**Amount Spent** (June 30th, 2011)	**Balance** (June 30, 2011)	**Revised Results 2 Budget:** Revised as of April 7, 2011	**Amount Spent** (June 30th, 2011)	**Balance** (June 30, 2011)	**Revised Result 3 Budget:** Revised as of April 7, 2011	**Amount Spent** (June 30th, 2011)	**Balance** (June 30, 2011)	**Revised Result 4 Budget:** Revised as of April 7, 2011	**Amount Spent** (June 30th, 2011)	**Balance** (June 30, 2011)	**TOTAL BUDGET**	**TOTAL BALANCE**
	On the ground field experiments			Sampling and data set compilation			Sampling and data set compilation			Lab analysis and data synthesis complete			**330,000**	**330,000**
BUDGET ITEM														
PERSONNEL: wages and benefits (Civil service staff ordering materials, preparing plots, coordinating efforts with BioCON and B4WARMED managers to install new plots, maintain ongoing plots, collect baseline samples and manage data. 2009-10 treatments were applied, measurements, data and samples were collected in all experiments.Sample processing for analysis is underway.)	35,708	35,708	0	67,200	67,200	0	89,234	89,234	0	66,000	66,000	0	258,142	0
Other direct operating costs (Carbon Dioxide gas and rental on CO_2 delivery system)				22,581	22,581	0	21,851	21,851	0	0	0	0	44,432	0
***Field supplies**: labels, sample bags & envelopes, plot tags, data sheets,, fertilizer, supplies for sample preparation and processing, consumables for soil flux (batteries, drierite, etc.) (Other supporting grants were used for supplies in results 2 because CO_2 use was high.)	2,082	2,082	0	0	0	0	3,249	3,249	0	0	0	0	5,331	0
***Travel** (in state to B4WARMED for maintenace, data collection & sampling.)	407	407	0	500	500	0	1,500	1,500	0	0	0	0	2,407	0
***Field equipment repair** (repair BioCON main CO_2 delivery valve)	689	689	0			0	0		0	0	0	0	689	0
Other (Chemical analyses of plants, soils)						0	0		0	19,000	19000	0	19,000	0
COLUMN TOTAL	**$38,885**	**$38,885**	**$0**	**$90,281**	**$90,281**	0	**$115,834**	**$115,834**	0	**$85,000**	**$85,000**	0	330,000	**0**