Research Addendum for Peer Review

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Switchgrass: Biofuel Production and Invasion Risk Management

Project number: **123-E**

Submitted by:

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I. Abstract

Native switchgrass has been selected and hybridized to establish dense, productive biofuel stands with little nutrient or water requirements. This major advance in biofuel sustainability also poses a risk to native biodiversity; selectively bred switchgrass shares many characteristics that typify our most invasive species. Little is known about the invasion risk posed by selective breeding of switchgrass for biofuel production.

Invasion risk assessment is urgently needed because switchgrass cultivars are being established widely across the state. **In activity #1**, we will evaluate switchgrass cultivar invasiveness in newly restored and remnant prairie. Using locally native switchgrass populations as a study control, we will quantify switchgrass cultivar establishment, biomass production, and impacts on native plant diversity. We will determine the relationship between invading switchgrass seed number and impacts to native biodiversity. These data will provide a quantitative assessment of which switchgrass cultivars and seeding density may allow for high biomass production with less risk of invasion in prairie. **In activity #2**, we will test two strategies to manage potentially invasive switchgrass cultivars. Several mowing regimes and tree windrows will be tested to contain switchgrass cultivars in biofuel production fields. Results from these two activities will provide timely data to inform the emerging biofuel industry of potential invasive risks associated with switchgrass cultivars and options to manage such risks.

II. Background

Rising concern over climate change and energy independence has sparked vigorous research on biomass and biofuel production. Switchgrass was identified as an important biomass-producing crop because it is widely adapted and native in the US and it provides environmental benefits such as soil and wildlife conservation (Parrish and Fike 2005). To increase biofuel yields, breeding programs within the federal government, universities and private industry have developed and released high-yielding, drought tolerant switchgrass cultivars. Cultivars are unique varieties of the species that have been selected for desirable traits, tested for trait stability across generations, and shown to perform consistently within a defined geographic range (Aubry et al. 2005). Further switchgrass hybridization and breeding is expected to increase cultivar yields by 40% (Mitchell et al. 2008).

Switchgrass cultivars represent a major advance in the sustainable production of biofuels. Switchgrass has a high net energy yield, 540% more energy produced than consumed (Schmer et al. 2008). This is much greater than the estimated 34% net energy yield for corn ethanol (Shapouri et al. 2002). Switchgrass production fields also offer many environmental benefits including carbon sequestration, reduced soil erosion and improved water quality (McLauchlan et al. 2006, Nelson et al. 2006). Despite the numerous benefits associated with switchgrass cultivars, there are emerging concerns that development of high-yielding switchgrass cultivars may have the unintended consequence of enhancing switchgrass invasiveness (Simberloff 2008).

Some of our worst grass invasions resulted from the selective breeding and hybridization of multiple geographically isolated populations. Most notable and well known is the invasion of reed canary grass (*Phalaris arundinacea*) in wet lowlands throughout most of the US. Reed canary is native to the US; however, the introduction of agronomic cultivars from Europe and the recombination and reshuffling of genotypes contributed to the reed canary invasion (Lavergne and Molofsky 2007). Other native plants have become invasive or at least more competitive when populations are hybridized and/or selectively bred (Gustafson et al. 2004, Culley and Hardiman 2009). These cases are alarmingly similar to the protocols involved in switchgrass breeding programs: selection for high-yielding cultivars, hybridization among multiple populations, and introduction of non-local genotypes. Similar history between our most invasive grasses and switchgrass breeding programs raises concern for invasive impacts of switchgrass cultivars. However, no studies have tested their invasive potential. Invasion risk assessment is urgently needed because switchgrass cultivars are being planted across Minnesota and the United States without pre-screening or evaluation of risks.

A better understanding of the invasion risks associated with switchgrass biofuel crops would inform breeding programs and management strategies to mitigate such risks. For example, breeding programs could better manage invasion risks if we knew the specific relationships between selected traits of switchgrass cultivars (ie. establishment and production) and invasive impacts (Anderson et al. 2006). Management strategies could complement breeding programs by providing solutions for switchgrass control when breeding programs cannot minimize invasion risks without drastically comprising biomass yields. This research will provide insight on switchgrass risks, management, and production and offer recommendations to address ecological and agronomic challenges in the emerging biofuel industry.

This project will evaluate invasive risk and biomass production of selectively bred switchgrass as compared to locally native switchgrass populations. Switchgrass cultivars pose multiple threats; two of these will be addressed in our study. Our first objective is to determine whether switchgrass cultivars pose a threat to the establishment of diverse prairie for biofuel production. Biofuel production from diverse prairies may offer greater net energy yields and ecosystem services as compared to switchgrass monocultures (Tilman et al. 2006). We will test whether switchgrass cultivars dominate and reduce plant diversity in newly seeded prairie.

Our second objective is to quantify the impact of switchgrass cultivars on plant diversity in remnant prairies. Future efforts to expand switchgrass biofuel production may pose a significant threat to remnant prairies if switchgrass cultivars readily spread into remnants and impact plant diversity. We will evaluate switchgrass seed dispersal distance and the relationship between arriving switchgrass seed number and impacts on remnant prairie plant diversity. Our first two objectives will involve three switchgrass cultivars, six locally native populations, and two sites with soils representative of glacial outwash plains. This work will result in recommendations for appropriate switchgrass cultivars and seeding rates to mitigate invasive risks and impacts on native prairie biodiversity while allowing for high biofuel production.

Our third objective is to investigate the role of buffers and mowing in managing the spread and impact of switchgrass cultivars. The resulting recommendations will balance effective control with management cost and provide recommendations to mitigate potential risks associated with switchgrass cultivars.

III. Hypotheses – Our project will test the following hypotheses regarding switchgrass invasiveness and biomass production:

A. Switchgrass cultivars achieve greater dominance (density and biomass) than locally native switchgrass during the establishment/restoration of a new prairie. The degree of dominance varies for each cultivar.

B. Switchgrass cultivars reduce prairie plant diversity, but the effect varies for each cultivar.

C. The dominance and impacts of switchgrass (cultivars and locally native populations) intensify with increasing number of invading seeds. Cultivars become dominant at lower seed densities as compared to locally native switchgrass but the effect varies among cultivars.

D. Switchgrass cultivars can be controlled and contained through regular mowing and tree windrows.

IV. Methodology

Activity 1: Invasive Risk of Selectively Bred Switchgrass Budget: $95,000

Section A. Establishment Phase

Overview:

Little is known about the invasion risk of switchgrass cultivars. In section A, invasive risk will be assessed during the establishment of a new prairie. We will test the dominance of 3 switchgrass cultivars compared to 6 locally native switchgrass populations. Each switchgrass seed source will be introduced at 6 seed densities. The study will occur in 2 sites at the Ag and Energy Center of Central Lakes College in Staples, MN.

Seed:

In fall of 2011, switchgrass seed will be collected from 6 local native switchgrass populations within 75 miles of the Ag and Energy Center of Central Lakes College in Staples, MN. We will minimize the risk of genetic contamination by non-local switchgrass in several ways. First, we will collect from large switchgrass populations that are surrounded by areas with well documented agricultural and planting history. Second, we will confirm that there are no known CRP plantings within 1 km of our collection. Grass pollen dispersal distances are likely to be much lower than our 1 km buffer; one study suggested for a related grass that downwind pollen dispersal drops off precipitously after 100 m (Davis et al. 2004). Our standards exceed the rigor of current Minnesota Crop Improvement Agency standards for verifying origin-identified (yellow tag) native plant material for use in prairie restorations (MCIA 2010). Further, any potential contamination will likely be small and/or diluted by large local switchgrass populations.

Three switchgrass cultivars will be included: Forestburg, Sunburst, and Cave-in-Rock. An evaluation of switchgrass cultivar establishment, underway in 2010 and 2011, will be used to refine the final list of cultivars to focus to a suite that differs in productivity and potential invasiveness. This will lead to recommendations for selecting cultivars that produce high biomass yields while minimizing invasion risks.

We will use MnDOT seed mixture 350 (includes grasses and forbs) to establish a mixture of prairie species. This mixture is established widely across the state for prairie restorations. Switchgrass seed will be assigned to one of six seed densities (see below). Seed will be cold stratified in the winter prior to seeding in spring 2012.

Experimental Design:

This study will involve a full factorial of the treatments: Cultivar (3 types) versus locally native switchgrass (6 types) (9 total, referred from here on as “switchgrass types”) and 6 seed densities (25, 50, 100, 150, 250, and 350 seeds/ m^2). One m^2 plots of each switchgrass type and seed density will be established in the spring of 2012. Switchgrass seed will be incorporated with the MnDOT seed mixture 350 and be distributed evenly over each plot. Seed will be raked into the top 1 cm of soil to improve seed-to-soil contact and simulate conventional seed drilling techniques used to restore prairies. As a part of conventional management for newly seeded prairies, we will perform two to three herbicide treatments prior to seeding and we will mow annual weed cover as necessary to a height of 15 cm during the first year of establishment (2012).

We will replicate cultivar vs. non-cultivar plots at a 2:1 ratio. This will allow for more power to detect differences between specific cultivars whereas non-cultivars are considered random samples of a larger pool; therefore, we increased the number of native switchgrass populations versus replication within each population. The experimental design will be replicated twice within each site (144 plots/ field) and we will include two sites (288 total plots) at the Ag and Energy Center.

This study will be analyzed with a linear mixed effect model. Cultivar versus locally native switchgrass will be treated as fixed effects whereas each locally native switchgrass population (6) will be treated as random effects. Locally native switchgrass populations represent random samples of a larger statistical population (central Minnesota) thereby satisfying the requirements of a random effect. In contrast, each switchgrass cultivar will be treated as a fixed effect because preliminary data on biomass production for each cultivar will allow for specific, testable predictions of invasiveness among cultivars. This analysis will allow us to make specific inferences regarding the invasiveness of each cultivar. Our design includes more experimental units for each cultivar to improve statistical power to detect differences among cultivars. Site will be considered a random effect.

Seed density will be analyzed as a continuous fixed effect. We have chosen a wide range of seed inputs for several reasons. First, because a mixed model compares the slope and intercepts of a line fit to the data, added data along the line is a better use of experimental units as compared to more data at each point in the line. Second, this approach will shed more light on the relationship between arriving seed number and switchgrass dominance. A single seed level experiment could miss critical insight; the impacts of switchgrass cultivars are likely to vary with seed input and density dependence. Using Akaike's information criterion, we will test the fit of competing models that describe the shape of the curves. The proposed range of seed input brackets the seed densities recommended by MnDOT for planting a diverse prairie (50 seeds/ m^2) and for planting a switchgrass monoculture (~350 seeds/m^2).

Measurements:

In the first year of establishment (2012), we will measure plant diversity during late summer as percent cover of each species. In our experience, switchgrass and other prairie plants will have grown sufficiently by late summer to allow for plant identification. In the fall of year 1 (2012), we will harvest all senesced plant material and determine the biomass of each species. In year 2 (2013, post-establishment) we will repeat the same measurements. Our response variables for switchgrass are percent cover and biomass (percent switchgrass biomass). Our response variables for the entire plant community-plot are species richness and percent composition. We will use these data to calculate diversity indices for each plot.

Section B. Spread Phase

Overview:

In section B, we will determine the risk of switchgrass invading established, remnant prairie. The focus in section B is on grass cultivar invasion and impact in remnant prairie plant communities. To accommodate this objective we appropriately adjust our seeding methods (see below). We are allocating half of the experimental units to section B as compared to A. We justify this prioritization by pointing out that if switchgrass is not found to be invasive in the establishment phase (A), it is not likely to have a high risk of spreading into remnant prairie. Therefore, while section A was replicated twice in each of two sites, section B will have one set of experimental units in two remnant prairies at Cedar Creek Long-Term Ecological Research site. There will be a total of 144 experimental units dedicated to section B.

Seed:

In fall of 2011, switchgrass seed will be collected from 6 local native switchgrass populations in Cedar Creek LTER or within 75 miles. A focus will be placed on harvesting seed that is within 75 miles of Cedar Creek and the Ag Center so that it can be used in both locations. If seed is collected for use only in section B, we will use the same collections methods as in section A to verify locally native switchgrass populations.

The same three switchgrass cultivars included in section A will be used in B.

Experimental Design:

As in section A, this study will involve a full factorial of the treatments (fixed effects): Cultivar versus locally native switchgrass (9 total types) and 6 seed densities (25, 50, 100, 150, 250, and 350 seeds/ m^2). One m^2 plots of each switchgrass type and seed density will be established in two remnant prairies during the spring of 2012. This design will be replicated in two separate fields, 144 total plots at the Cedar Creek LTER.

Seeding and plot establishment methods will mimic a seed dispersal event into a remnant prairie. Therefore, in contrast to section A, we evenly distribute the seeds over each plot but we will not rake the seeds into the soil. Ideally we will establish the plots in fall 2011. However, seed collection will also occur in September and October of 2011; therefore, an early snowfall may block efforts to subsequently seed and establish these plots in fall 2011. If seeding is postponed until spring 2012, seeds will be cold stratified during the winter.

As in section A, this study will be analyzed using the same model structure in a linear mixed effect model. Despite relatively fewer experimental units in section B, 24 plots will be dedicated to testing each cultivar.

Measurements:

In the first year of establishment (2012), we will measure switchgrass density during late summer. In the fall of year 1, we will harvest all senesced plant material and determine the biomass of switchgrass and other prairie species. In year 2 (2013, post-establishment) we will measure percent cover of switchgrass and other species in late summer. In the fall of year 2, we will harvest all senesced plant material.

Activity 2: Invasion Risk Management **Budget: $25,000**

In activity 2 we will test two strategies for controlling switchgrass cultivars: mowing and buffer composition.

Mow Treatments:

We will test the efficacy of mowing to control switchgrass cultivars. Mow treatments will involve cutting established stands of switchgrass cultivars to a height of 5-10 cm. Through a NexGen grant plots of Forestburg switchgrass were established at the Ag and Energy Center in 2009.

We will establish or locate plots for two additional switchgrass cultivars within 50 miles of the Ag and Energy Center. Each plot will be 4 m^2. Preferably they will be the same cultivars used in activity #1. For each cultivar (3 cultivars total), we will assign the following three treatments: no mow (control), mowed in early summer, mowed in late summer, and mowed in both early and late summer. Mowing times are designed to target specific life history stages: early summer and late summer mowing removes basal and flowering stalks (plus basal leaves), respectively. Consecutive within-season mowing has been shown to reduce switchgrass vigor (Cuomo et al. 1998) but the potential for mowing to reduce invasiveness remains less clear. This experiment will be replicated four times per cultivar (16 experimental units/ cultivar). We will perform these treatments in 2011 and 2012.

Mowing Measurements:

We will measure height and stem density of switchgrass cultivars in the spring of 2012 and 2013; each measurement will assess the previous year treatment effects. A final measurement of switchgrass biomass will be collected after senescence in the fall of 2013. The data will be analyzed with ANOVA.

Buffer Treatments:

We will test the effect of aspen (*Populus tremuloides*) windrows in preventing the spread of switchgrass cultivars. Aspen was selected as the windrow species because it is fast-growing and common in north-central Minnesota. Our windrow consists of three rows of trees, 6 meter width, and 20 meter height. For this study, the windrow will be located to the east of the plots. Future research will test windrows located to the north, south, and west of plots.

Three switchgrass cultivars will be planted in 1 m^2 plots (250 seeds/ m^2) during the spring of 2012 at varying distances from the edge of the aspen windrow (8 meters, 2 meters, windrow edge, and 2 meters into the windrow). By varying planting distances in relation to the windrow we intend to mimic a dispersal event of seeds into the windrow, and test the capacity of windrows to suppress the establishment and spread of switchgrass. The same three cultivars used in activity #1 will be used in this study. Each set of distances will be replicated three times per switchgrass cultivar (3 cultivars X 4 distances X 3 replications = 36 experimental units). This simple design will allow us to determine the effects of a windrow buffer in containing switchgrass cultivars and minimizing spread.

Buffer Measurements:

In the first year of establishment (2012), we will measure establishment as the density of switchgrass seedlings. In the fall of year 1, we will harvest all senesced switchgrass and determine switchgrass biomass. In fall of year 2 (2013, post-establishment), we will harvest all senesced switchgrass and determine switchgrass biomass. We will evaluate the impacts of the windrow by regular measurements of light penetration across the season and in relation to distance to the windrow. The data will be analyzed with ANOVA.

V. Results and Deliverables

This study will inform ecologically sensitive biofuel policies, provide insight on the emerging issue of invasive biofuel crops, and offer on-the-ground recommendations to land managers involved in biofuel production. **Activity #1** will provide a quantitative assessment of invasion risk in newly established and remnant prairies. Our results will illuminate which cultivars and what seed densities impact restored prairies and potentially lead to dominance in remnant prairies. **Activity #2** will offer practical strategies to mitigate the potential risks associated with switchgrass cultivars. Both activities will provide data that will be organized into manuscripts and submitted to peer-reviewed bioenergy or ecology journals.

VI. Timetable

Activity 1: Invasive Risk of Selectively Bred Switchgrass

Date	**Activity**
Fall 2011	Collect switchgrass seed from a minimum of 6 locally native sources
April-May 2012	Establish experimental treatments.
August 2012	Quantify switchgrass and other prairie plant percent cover
Fall 2012	Quantify first-year biomass production by species
August 2013	Quantify switchgrass and other prairie plant percent cover
Fall 2013	Quantify final biomass production by species
December 2013	Analyze results and provide final report

Activity 2: Invasion Risk Management

Date	**Activity**
July 2011	Establish mowing treatments
August 2011	Continue mowing treatments
Spring 2012	First measurements on mowing treatments; Establishment buffer treatments
Summer 2012	Continue mowing treatments; Conduct field day demonstration
Fall 2012	First measurements on buffer treatments
Spring 2013	Second measurement on mowing treatments
Summer 2013	Conduct field day demonstration
Fall 2013	Final measurements on mowing and buffer treatments
December 2013	Analyze results and provide final report

Future Research:

We will pursue federal and state funds, including funding through a Ph. D. dissertation program at the University of Minnesota (J. Eckberg), to expand this research. In future studies we intend to quantify dispersal distance and the dispersal kernel of switchgrass seeds. We will also conduct long-term monitoring for up to four years to track changes in prairie diversity and productivity. As funding becomes available we will expand this study to other ecological regions of the state including west-central and south-central Minnesota.

VII. Budget

Robert Schafer and Jim Eckberg will serve as co-project managers and they will be responsible for coordinating all aspects of this project. Jim will oversee the development of experimental protocols, treatment establishment, data collection, analysis, written and oral presentation of results to the LCCMR, and preparing results for publication in peer-reviewed journals. Robert is based at Central Lakes College- Ag and Energy Center. He will oversee the maintenance of experimental plots, financial accounting with MNSCU system, and outreach and dissemination of information to the agricultural community.

Shelby Flint, a graduate student at the U of M, is conducting complementary research to this project. Her data will allow us to focus our experimental design on the more aggressive switchgrass cultivars. Shelby and Jim will collaborate on the development of experimental protocols, analysis, and preparation of results for publication. Drs. Ruth Shaw and Neil Anderson have specific expertise and knowledge in this area of ecology. They will provide guidance on the development of the project, and collaborate on the write-up and submission of manuscripts to peer-reviewed journals. Michelle Johnson is based at the based at the Ag and Energy Center. She will assist Jim and Robert with implementing experimental protocols and collecting data.

Other expenses include travel, seed and herbicide, and equipment use. Spraying and planting equipment costs includes maintenance of a boom sprayer, harrow, plow, and tractor owned by Central Lakes College. This equipment is necessary for site preparation to prepare the site for seeding and maintain experimental treatments. This study will be travel intensive; the Ag and Energy Center is approximately 150 miles from the University of Minnesota. Locating and collecting seed from switchgrass populations will also be mileage intensive.

2011-2012 Detailed Project Budget

TOTAL TRUST FUND REQUEST BUDGET 2.5 years

BUDGET ITEM	-	
Personnel:	**Grant**	-
Robert Schafer, Co-project manager, Annual Salary $56,523 plus fringe $24,916 = $81,439 x 0.06 FT = $4,886 x 2.5 years	$ 12,216	
Michelle Johnson, Research Technician Annual Salary $27,266 plus fringe $19,463 = $46,729 x 0.12 FT = $5,608 x 2.5 years	14,019	
Contractual / Professional Services:		
Jim Eckberg, Co-project manager, oversee the project consultation, research protocols and publications and professional writing	$ 45,000	

Shelby Flint, develop research protocols, data collection, and publication	$ 12,000
Dr. Ruth Shaw, Consulting	9,000
Dr. Neil Anderson, Consulting	9,000
Equipment/Tools/Supplies:	
Seed, Herbicide	$ 3,422
Planting, spraying, and mowing equipment	4,000
Travel:	
Ag Center Travel for Project Managers and Collaborators (300 round-trip travel miles from University of Minnesota to the Ag Center). Number of U of M to Ag Center visits per year (11) x round-trip travel (300 miles) x 2.5 years = 8,250 miles. Find 6 appropriate seed collection sites in north-central MN: up to 20 site visits x 150 miles RT each = 3,000 miles. Seed collection from 6 appropriate sites: 6 sites X 150 miles RT x 3 visits = 2,700 miles. Bi-weekly plot maintenance by Ag Center technician for off-site plots: 2 sites x 27 weeks x 2.5 years x 16.3 miles RT = 2,196 miles. Bi-weekly plot maintenance at Cedar Creek Natural History Area: 27 weeks x 2.5 years x 68 miles = 4,590 miles. 20,736 total miles x .50/mile	$ 10,368
Additional Budget Items:	
Annual Field Days (2 field days in total) will include tours, educational seminars for farmers, educators, industry and Gov't Agencies estimated cost per event including guest speakers, facilities and set-up = $300/event	$ 600
Materials and publication of newsletters (1 issues per year)	375
TOTAL ENVIRONMENT & NATURAL RESOURCES TRUST FUND $ REQUEST	**$ 120,000**

OTHER FUNDS

SOURCE OF FUNDS	**AMOUNT**	**Status**
In-kind Services During Project Period:	-	
Central Lakes College Ag Center land, facilities and incidental equipment	6,000	Secured

VIII. Dissemination and Use

These results will be used to assess invasion risks and select appropriate grass seed sources to support the emerging biofuel industry. Results and recommendations from this study will be disseminated to farmers, educators, industry, universities, and government agencies through two annual field demonstration days, email lists, web sites, newsletters and peer-reviewed journal articles.

IX. Credentials

Co-Project Manager: Jim O. Eckberg

Research Fellow, Department of Soil, Water and Climate, University of Minnesota

Education **Masters of Science**, *University of Nebraska*, Lincoln, NE, August 2008.
Major: Ecology GPA: 3.5.

Bachelor of Arts, *Gustavus Adolphus College*, St Peter, MN, May 2004.
Major: Biology GPA: 3.51

Experience **Research Fellow,** University of Minnesota, Saint Paul, MN, 2009-present. Development of best management practices for biofuel crops: perennial prairie grasses, miscanthus, camelina, sweet sorghum and pennycress.

Jim Eckberg is a research fellow at the University of Minnesota. Jim's Masters research addressed the role of native insects as an alternative means to control noxious weeds, specifically bull thistle. His research demonstrated that native insects can prevent bull thistle from becoming invasive, an ecosystem service that has gone unnoticed in the absence of any thistle problems. Jim has designed and implemented multi-site invasion studies, constructed demographic models to predict invasive population growth, and has published scientific papers on plant population dynamics and invasions.

As the project manager, Jim will be responsible for coordinating research to address the emerging issue of invasive biofuel crops. Jim will collaborate with Dr. Ruth Shaw, Dr. Neil Anderson and Shelby Flint; their combined experience in selective breeding, invasiveness and genetics will help guide the development of studies to illuminate the potential for engineered invasiveness in biofuel crops. Jim's experience with on-the-ground invasion tests and use of field data to construct invasion models will be instrumental to understanding potential impacts of invasive biofuel crops on native biodiversity. Jim has extensive statistical training including model selection (AIC) and mixed models. As a Udall Scholar in environmental policy, Jim is highly interested in using this research to inform ecologically sensitive bioenergy policies.

Selected Honors & Awards

2008 Nebraska Invasive Species Conference - 1st Place Poster
2006-07 A. W. Sampson Rangeland Fellowship - $18,000
2005 Weaver Competitive Grant, Nature Conservancy - $1,000
2004-06 Life Sciences Interdisciplinary Fellowship - $36,000
2003 Morris K. Udall Scholarship, U.S. Congress- $5,000

Publications

Eckberg, J.O., E.A. Bockman, and P.M. Kittelson. 2007. Adding Nitrogen Controls Yellow Sweetclover in Common Garden Study (Minnesota). *Ecological Restoration*. 25:279-281.

Tenhumberg, B., S.M. Louda, J.O. Eckberg and M. Takahashi. 2008. Monte Carlo analysis of parameter uncertainty in matrix models for the weed *Cirsium vulgare*. *Journal of Applied Ecology*. 45: 438-447.

Miller, T.E.X., S.M. Louda, K.A. Rose, and J.O. Eckberg. 2009. Impacts of insect herbivory on cactus population dynamics and distribution: Experimental demography across an environmental gradient. *Ecological Monographs*. 79: 155-172.

Co-Project Manager: Robert Schafer
Director, Ag and Energy Center, Central Lakes College, Staples, MN

Education **Bachelor of Science**, *University of Wisconsin*, River Falls, WI, 1979.
Major: Agricultural Education

Plant Process Technology – Ethanol Production, Minnesota West Tech College, Granite Falls, MN, 2002.

Bob Schafer is the Director at Central Lakes College Ag and Energy Center. Bob was the project manager on the NextGen Grant - Dedicated Energy Crop Production. This involved the establishment of 45 acres of perennial grass plots (including 'Forestburg' Switchgrass) across 9 sites in the central sand plans. Bob is also testing cold strain varieties of Miscanthus for potential high yield biomass. He was the co-project manager for the LCCMR grant - Improving Water Quality on the Central Sands, which is studying ways to reduce nitrate and phosphorus losses to groundwater and surface waters of this sandy eco-region. He headed a college engineering research team that disproved early solar ethanol distillation methods. While employed for five years in the corn ethanol business he participated in starting three dry grind ethanol plants where he advanced to plant manager of a 110 mgy facility. He hired and trained production crews, oversaw plant construction, established standard operating procedures, optimized production and reduced operation costs. Bob Schafer and the Energy Center are well connected to biofuel producers, industry and agriculture in the region of our study.

Research Experience
University of Wisconsin Jan-June 1979
Ag Engineering Dept – Fuel Ethanol

- Built and demonstrated a Solar Still disproving its feasibility.
- Processed corn and conducted fermentation trials

Central Lakes College Ag Center, Staples MN Nov 2008
Project Manager NextGen Grant- Dedicated Energy Crop Production

- Established nine plots totaling 45 acres of Perennials for biomass
- Planted and harvested 12 acres of Camelina oilseed crop for biodiesel
- Established a trial planting of cold strain Miscanthus

Co-Project Mgr LCMR grant – Improving Water Quality on the Central Sands May 2008

- Project is studying ways to reduce nitrate and phosphorus losses to groundwater and surface waters on the Central Sands.

Ruth Geyer Shaw
Professor, Department of Ecology, Evolution, and Behavior, University of Minnesota

Education and Experience:

B.A. Biology	1976	Oberlin College, Oberlin, Ohio;
Ph.D. Botany and Genetics	1983	Duke University, N. Carolina
Post-doctoral in Genetics	1984-1986	University of Washington, NIH Fellow
Asst Professor	1987-1992	University of California, Riverside
Asst, Assoc, Full Professor	1993-present	University of Minnesota, Twin Cities
Sabbatical	1995-6	Edinburgh University
Guggenheim Fellow	2002-3	Université de Montpellier, France

Throughout my career, my research has addressed fundamental questions regarding adaptation in native plant populations and has also yielded guidance for managing impacts of human disturbance, including climate change, introduction of invasive plants, and fragmentation of populations into small remnants. In over 17 yr at UM, I have mentored graduate students' experimental studies of adaptation in prairie plant populations, and for 10 yr I have led UM's participation in an NSF-funded long-term experimental study investigating the evolutionary consequences of severe fragmentation of prairie populations of purple coneflower, *Echinacea angustifolia* (collaboration with Dr. S. Wagenius of the Chicago Botanic Garden, see http://echinacea.umn.edu). Among the key results of these studies are demonstration of: degree of local adaptation to present-day habitats and limits to rates of adaptation to climate change in partridge pea, *Chamaecrista fasciculata*[1,2], dramatic reduction in seed production of progeny from crosses between prairie plant populations[3], large differences in survival and fecundity among remnant populations[4], and exceptionally severe inbreeding depression affecting growth and survival in purple conflower[5,6] (selected references in leading scientific journals below). Moreover, my colleagues and I have recently developed an approach for analyzing data on individual survival and fecundity, the fundamental measures of adaptation[4,5]. This new approach provides far more precise inferences about adaptation than previously possible. I have been honored with positions of leadership in scientific organizations, including the Society for the Study of Evolution and the American Society of Naturalists.

[1]Etterson, J. R. and R. G. Shaw. 2001. Constraint to adaptive evolution in response to global warming. Science 294: 151-154. [2]Davis, M.B. and R. G. Shaw. 2001. Range shifts and adaptive responses to quaternary climate change. Science 292: 673-679. [3]Heiser, D.A. and R.G. Shaw. 2006. The fitness effects of outcrossing in *Calylophus serrulatus*, a permanent translocation heterozygote. Evolution 60:64-76. [4]Geyer, C. J., S. Wagenius, and R. G. Shaw. 2007. Aster models for life history analysis. Biometrika, 94: 415-426. [5]Shaw, R.G., et al. 2008. Unifying life history analyses for inference of fitness and population growth. The American Naturalist 172: E35-E47. [6] Wagenius, et al. 2010. Evolution 64:761-771.

Organization Description: The mission of the University of Minnesota's Department of Ecology, Evolution and Behavior is to advance and disseminate knowledge in these fields through excellence in theoretical, experimental, and field research; undergraduate and graduate education; scholarly activities; and outreach. The integration of this knowledge across levels of biological complexity is a prerequisite to addressing many of the biological and environmental challenges facing society. http://www.cbs.umn.edu/eeb/

Neil O. Anderson
Associate Professor, Department of Horticultural Science, University of Minnesota

Professional Preparation:
California Polytechnic State University, San Luis Obispo, Ornamental Horticulture, B.S. 1983
University of Minnesota, Horticulture, M.S. 1985 (Minor: Plant Breeding)
University of Minnesota, Horticulture, Ph.D. 1989 (Minor: Plant Breeding)

Appointments:
Associate Professor, Dept. of Horticultural Science, University of Minnesota, 2004-present
Assistant Professor, Dept. of Horticultural Science, University of Minnesota, 1999-2004
Flower Breeder, Potted Plant Product Manager, & New Crop Development Specialist, PanAmerican Seed Company, 1997-1999
University of Minnesota, Postdoctoral Research Associate, Horticultural Science, 1989-1997
University of Minnesota, Research Associate, Horticultural Science, 1983-1989

Neil Anderson has researched invasion biology since 1989, focusing on commercial cultivars, breeding and selection against invasiveness by plant breeding programs, and risk assessment. He is currently conducting molecular diversity and competition research on reed canarygrass (Phalaris arundinacea), focusing particularly on the invasion risks of reed canarygrass grown for biofuel purposes. Dr. Anderson is an expert in plant reproductive biology, plant breeding and genetics, molecular biology, risk assessment, and consequences of hybridization between wild populations and cultivated crops.

Five Relevant Publications:
Anderson, N.O. and P.D. Ascher. 2000. Fecundity and fitness in cross-compatible pollinations of tristylous North American *Lythrum salicaria* populations. Theoretical and Applied Genetics 101:830-843.

Smith, A.G. and N.O. Anderson. 2006. Engineered sterility for non-native plant invaders. II:232-239. In: J.A. Teixeira da Silva (Ed.), Floriculture, Ornamental and Plant Biotechnology: Advances and topical issues, Global Science Books, London.

Anderson, N.O., S.M. Galatowitsch, and N. Gomez. 2006. Selection strategies to reduce invasive potential in introduced plants. Euphytica 148:203-216.

Pietsch, G.M., N.O. Anderson, and P.H. Li. 2009. Cold tolerance and short day acclimation in perennial *Gaura coccinea* and *G. drummondii*. Scientia Horticulturae 120:418-425.
Anderson, N.O., A. Younis, and E. Opitz. 2009. Development of colored, non-vernalization requiring seed-propagated lilies. Acta Horticulturae 836:193-198.

Drew, J., N.O. Anderson, and D. Andow. 2010. Conundrums of a complex vector for invasive species: A detailed examination of the horticultural industry. Biological Invasions DOI 10.1007/s10530-010-9689-8. http://www.springerlink.com/content/0642h37ru3413821/

Synergistic Activities:
Director, Invasion Biology Research Consortium, 2001-present.
Senior Personnel, NSF, DGE-IGERT grant “Risk Analysis for Introduced Species and Genotypes” 2007-2012
Graduate Program Advising: Applied Plant Sciences, Conservation Biology, Plant Biological Sciences, Introduced Species and Genotypes (Minor)

Nicholas Jordan

Professional Preparations

Harvard College	1974-1979, A.B., Biology, High Honors
Duke University	1980-1986, Ph.D., Botany and Genetics

Appointments

Assistant, Associate and Professor, Agronomy & Plant Genetics Dept., UMN-TC, 1994-
Assistant, Associate Professor, Division of Science, Truman State Univ. (1986-1994)

Nick Jordan is a plant ecologist, interested in invasion plant ecology and with a particular focus on interactions between soil microbes, especially mycorrhizal fungi, and invasive plants, and in landscape-scale patterns and processes affecting plant invasion.

Selected Relevant Grants

USDA: Managing Weed Invasion in Diversified Biofuel Grasslands: The Interplay of Soil Microbes, Nurse Species and Nitrogen. Jordan, Kinkel, Sheaffer, Aldrich-Wolf, Wyatt. $493,000, 2010-2012

USDA CIG Spatial modeling and collaborative landscape design to improve nutrient management, agricultural productivity, and ecosystem services in the Mississippi River Basin. Jordan. $314,811, 2011-2013.

USDA-NIFA-AFRI. Precision zonal management systems for resilient cereal yields and ecosystem services under variable climates. Jordan et al. $4,119,504, 2011-2015.

Selected Relevant Publications

Jordan, N., Zhang, J. and Huerd, S 2000. Arbuscular-mycorrhizal fungi: potential roles in weed management. Weed Research 40:397-410.

Blumenthal, D. M., N. R. Jordan, and E. L. Svenson. 2005. Prairie restoration inhibits weed invasion. Agriculture, Ecosystems and Environment 107 (2-3): 221-230

De Bruin, J.L, Jordan, N, Porter, P.M., and S.C Huerd. 2006. Soil Microbiota Effects on Rye Growth: Implications for Integration of a Rye Cover Crop into Temperate Cropping Systems. Renewable Agriculture and Food Systems: 21(4); 245–252

Jordan, N., Larson, D. and S. Huerd. 2008. Soil modification by invasive plants: effects on native and invasive species of mixed-grass prairies. Biological Invasions 10:177-190.

Jordan, N. and S. Huerd. 2008. Effects of Soil Fungi on Weed Communities in a Corn-soybean Rotation. Renewable Agriculture and Food Systems 23:108-117.

Jordan, N., Larson, D. and S. Huerd. 2010. Evidence of qualitative differences between soil-occupancy effects of non-native versus native grassland plant species. Invasive Plant Science and Management 4:(in press).

Shelby A. Flint
Graduate Student, Conservation Biology Graduate Program - Risk Analysis for Introduced Species and Genotypes IGERT, University of Minnesota

Education	**Master of Science**, Water Resources, 2007, University of New Hampshire Thesis: The Impact of Palustrine Wetlands on Surface Water Quality in the Lamprey River Watershed, NH
	Bachelor of Arts, Political Science and Women's Studies, *summa cum laude,* with honors, 1993, University of Arizona.
	Associate of Arts, Liberal Studies, 1987, Simon's Rock College

Shelby Flint is a third-year Ph.D. student in the Conservation Biology Graduate Program at the University of Minnesota-Twin Cities. She is also part of a NSF-funded interdisciplinary training program, the Risk Analysis for Introduced Species and Genotypes Integrative Graduate Education and Research Traineeship (ISG-IGERT). Her training in the ISG-IGERT has equipped her to address questions of ecological risks posed by the introduction of novel organisms or varieties. Her Ph.D. research investigates the genetic variability and degree of deliberate selection in commercially-available varieties of switchgrass (*Panicum virgatum*), the establishment and performance of these varieties at four field sites in Minnesota (Waseca, St. Paul, Staples, and Morris), and the degree to which these four different environments impact variety performance (genotype x environment interactions). Results from this work will be used to further develop the proposed project and focus on the commercially-available switchgrass varieties that pose the greatest invasive potential in Minnesota.

Awards and Honors

- National Science Foundation IGERT Fellow, University of Minnesota, 2009-2011
- Graduate School Fellow, University of Minnesota, 2008-2009, 2011-2013
- Conservation Biology Summer Fellowship, 2009
- Dean's List with Highest Academic Distinction, University of Arizona, 1991-2
- Navy Wives' Club Scholarship, 1984-1987
- "Right Risks: Ethics and Ecological Risk Assessment" Symposium - $7,000
  Sponsored by the NSF-IGERT for Risk Analysis for Introduced Species and Genotypes, University of Minnesota

Publications

- A Wildlife Perspective: Bisphenol A Exposure, Effects, and Policy (*in prep.*, co-authors T. Markle, S. Thompson, and L. Wallace
- Dissolved Nitrogen and Carbon Affected by Temperature and Input Concentrations in Headwater Wetlands of a Sub-urbanizing Watershed (*in prep.*, co-author William H. McDowell)

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Aubry, C., R. Shoal, and V. Erickson. 2005. Grass cultivars: Their origins, development, and use on national forests and grasslands in the Pacific Northwest.*in* U.-F. Service, editor., Olympia.

Culley, T. and N. Hardiman. 2009. The role of intraspecific hybridization in the evolution of invasiveness: a case study of the ornamental pear tree *Pyrus calleryana*. Biological Invasions **11**:1107-1119.

Cuomo, G. J., B. E. Anderson, and L. J. Young. 1998. Harvest frequency and burning effects on vigor of native grasses. Journal of Range Management **51**:32-36.

Davis, H. G., C. M. Taylor, J. G. Lambrinos, D. R. Strong, and H. A. Mooney. 2004. Pollen limitation causes an allee effect in a wind-pollinated invasive grass (*Spartina altnerniflora*). Proceedings of the National Academy of Science **101**:13804-13807.

Gustafson, D. J., D. J. Gibson, and D. L. Nickrent. 2004. Competitive Relationships of Andropogon gerardii (Big Bluestem) from Remnant and Restored Native Populations and Select Cultivated Varieties Functional Ecology **18**:451-457.

Lavergne, S. and J. Molofsky. 2007. Increase genetic variation and evolutionary potential drive the success of an invasive grass. Proceedings of the National Academy of Science **104**:3883-3888.

MCIA. 2010. Native grasses and forbs pre-variety germplasm standards. Page 14, Minnesota Crop Improvement Agency.

McLauchlan, K., S. Hobbie, and W. M. Post. 2006. Conversion from agriculture to grassland builds soil organic matter on decadal timescales. Ecological Applications **16**:143-153.

Mitchell, R. B., K. P. Vogel, and G. Sarath. 2008. Managing and enhancing switchgrass as a bioenergy feedstock. Biofuels, Bioproducts, and Biorefining **2**:530-539.

Nelson, R. G., J. C. Ascough, and M. R. Langemeier. 2006. Environmental and economic analysis of switcgrass production for water quality improvement in northeast Kansas. Journal of Environmental Management **79**:336-347.

Parrish, D. J. and J. H. Fike. 2005. The biology and agronomy of switchgrass for biofuels. Critical Reviews in Plant Sciences **24**:423-459.

Schmer, M. R., K. P. Vogel, R. B. Mitchell, and R. K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass. Proceedings of the National Academy of Science **105**:464-469.

Shapouri, H., J. A. Duffield, and M. Wang. 2002. The energy balance of corn ethanol: An update.*in* U. S. D. o. Agriculture, editor.

Simberloff, D. 2008. Invasion biologists and the biofuels boom: Cassandras or colleagues? Weed Science **56**:867-872.

Tilman, D., J. Hill, and C. Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science **314**:1598-1600.