AN AGROECOLOGICAL APPROACH TO INCORPORATING NATIVE WARM-SEASON GRASSES INTO WISCONSIN FARMS

By

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DEDICATION

To my Dad, whose example taught me the importance of helping others and who nurtured my curiosity of the world.

To Dr. Winifred Dickinson, who challenged and encouraged me to apply rigorous science to that curiosity.

To my Paraguayan family, who showed me the human face of agriculture and who revealed to me the beauty of simplicity.

And to little Paul Anthony, who helps me to appreciate it all.

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ABSTRACT

Managed grazing for livestock production is a growing enterprise in the temperate United States. Most grass-based farmers sow non-native species and manage for low-diversity plant assemblages. However, higher plant functional group diversity in pastures has potential benefits. We employed an agroecological research framework by formulating specific social, ecological, and agronomic research objectives related to the incorporation of native warm-season grasses into Wisconsin farms. First, we constructed a written questionnaire assessing Wisconsin farmer attitudes towards and perceptions of native grasses. Thirty-five percent of farmers indicated that they are interested in native grasses for pasture use, but a large majority of respondents reported that they are unfamiliar with the identification and establishment of native grasses. The most important predictor of farmer interest in native grasses was their perception of how native grasses affect the environment. Second, in a field experiment, three native warm-season grasses were drill-seeded into an existing cool-season pasture at two times (spring and fall), and combinations of disturbance (grazing and burning) and soil amendments (nitrogen, carbon, and ambient) were applied to promote their establishment. Native grasses did not establish where nitrogen was applied, and the carbon amendment limited the rate of recruitment compared to the ambient treatment. For non-nitrogen plots, establishment was greater under burning vs. grazing but did not differ between seeding times. An ordination analysis showed that shifts in the plant community were driven more by treatments than by environmental factors. Treatments also affected pasture production, but the nature of the effect varied by year. Over 50% of the variability within forage quality parameters was attributed to non-management variables. Third, a greenhouse experiment that tested how defoliation timing and intensity affected production of smooth brome (cool-season) and big bluestem (warm-season) grasses showed different treatment

effects on similar metrics: total available forage and aboveground production. Smooth brome produced more total biomass, although during late-summer months big bluestem yielded more available forage. There were challenges to this interdisciplinary approach, but in addition to generating information that informs plant ecology theory and farm management, it allowed us to target gaps in current research and better understand agroecosystems as a whole.

GENERAL INTRODUCTION

"Conservation means harmony between men and land. When land does well for its owner,
and the owner does well by his land, when both end up better by the partnership,
we have conservation."

Aldo Leopold

Society is asking farmers to manage for multiple ecosystem services. In addition to producing food, fuel, and fiber, we expect farms to store soil carbon, purify water, support wildlife and plant diversity, and provide aesthetically appealing landscapes. Farmers need management options that simultaneously address these goals. There has been an increase in grass-based farming and prairie restoration efforts in the United States, presenting a unique opportunity to blend restoration/conservation efforts with agricultural production by incorporating native prairie grasses into grazing systems. This approach has potential agronomic (improved forage quantity and seasonal distribution), ecological (increased genetic diversity and ecosystem function), and social (niche markets and promotion of farmers as land stewards) benefits.

The main goal of this research was the establishment of native, warm-season (C4) grasses into existing pastures dominated by exotic, cool-season (C3) species. More broadly, we desired to gain a better understanding of 1) farmer interest in using native grasses and 2) the effects of prairie restoration management on the ecological and agronomic dynamics of grassland ecosystems. To address these interdisciplinary aspects—and generate results that would inform both grassland management and plant ecology theory—we employed an agroecological approach that incorporated the following research objectives:

Social

- Develop an understanding of current native grass use on Wisconsin grazing farms
- Assess farmer attitudes towards and perceptions of native grass use in pastures

Ecological

- Use plant ecology theory to target management to promote C3-C4 grass coexistence
- Assess the ability of treatments to facilitate establishment of native C4 grasses into existing C3 pastures
- Monitor plant community and nutrient responses to treatments to further our understanding of temperate grassland ecosystems

Agronomic

- Measure forage quantity and quality under management aimed at C4 grass establishment
- Compare C3 and C4 grass production under various defoliation regimes

A questionnaire was constructed and sent to 800 Wisconsin grass-based farmers to assess the social component of our research (Chapter 1). We conducted a field experiment to test specific hypotheses related to our ecological objectives (Chapters 2 and 3), and the agronomic objectives were fulfilled using this same field experiment (Chapter 4) as well as a greenhouse study (Chapter 5). This dissertation conveys results from the survey and experiments and concludes with a critique on the agroecological approach that was utilized.

Chapter 1. Why would a farmer consider native grasses for grazed temperate pastures?

ABSTRACT

More tallgrass prairie has been lost than any other terrestrial ecosystem and relict tallgrass prairie in the United States remains a threatened plant community. There are potential environmental and agronomic benefits to the reintroduction of native prairie warm-season grass species into grazing systems, but these can only be realized if farmers are willing to use native grasses. Because of the important relationship between farmer attitudes and conservation behaviors, we assessed grass-based farmer attitudes towards and perceptions of native grasses. We held focus groups with farmers to clarify grazing terminology and concepts and then developed a written questionnaire that was reviewed by experts in the fields of applied social research, survey methodology, and farming systems before being pilot-tested on a small group of farmers. In February 2006, we mailed the questionnaire to 800 Wisconsin grass-based farmers. We created indices and used descriptive statistics to interpret the results. We show how a tool (classification tree) commonly used to analyze complex ecological data can be used to interpret survey data. Thirty-five percent of respondents said they are interested in native grasses for pasture use. However, the large majority of farmers reported that they are unfamiliar with the identification and establishment of native grasses. The most important predictor of farmer interest in native grasses was their perception of how native grasses affect the environment. Both environmental and financial factors were ranked as highly important to farmers when considering the implementation of conservation projects. Our results show that environmental concerns are important to farmers. They also highlight the need to improve our understanding of how native grasses affect ecosystem services and to educate farmers about native grass use and

establishment. Using an interdisciplinary approach, we broadened the scope of grassland research while providing results that can be used by multiple groups, e.g., agronomists, conservationists, ecologists, and policy-makers. Understanding farmer attitudes at the local level should help to build successful, incentive-based conservation programs and inform research projects and policy initiatives aimed at blending natural resource and agronomic goals.

INTRODUCTION

More tallgrass prairie has been lost than any other terrestrial ecosystem (Samson and Knopf, 1994) and the remaining relict tallgrass prairie in the United States is a threatened plant community. At the time of European settlement, approximately 850,000 ha of prairie existed in Wisconsin (Curtis, 1959)—now only 809 ha remain (Cochrane and Iltis, 2000). This is mainly the result of farmland conversion in the late 19th and early 20th centuries (Rhemtulla et al., 2007). These prairies were dominated by warm-season (C4 photosynthesis) grasses, including A*ndropogon gerardii* Vitman (big bluestem), *Panicum virgatum* L. (switchgrass), and *Sorghastrum nutans* (L.) Nash (indiangrass). The extent of tallgrass prairie ecosystem loss has had profound ecological consequences (Rhemtulla et al., 2007), which has driven a growing prairie restoration enterprise and motivated research into how best to facilitate re-introduction of native species (Brye et al., 2002; Averett et al., 2004).

A limiting factor in plant conservation or restoration efforts can be the amount and condition of available land. Protected and refuge areas are threatened by increasing anthropogenic pressures (DeFries et al., 2007). They often occur in patchy distributions across the landscape (Rosenzweig, 2003), and there is growing awareness of the need to facilitate habitat connectivity across the landscape (Western, 2001; Hilderbrand et al., 2005). In the United States, 52% of the land area is used for agricultural purposes (USDA-ERS, 2002). Bringing conservation projects to agricultural lands would exponentially increase the amount of land available for conservation efforts and connect plant communities across the landscape, aiding in the recovery and preservation of native species. Working with land owners on conservation efforts has worldwide application as 80% of total land mass in most countries is privately owned (Environmental Law Institute, 2003).

Recognition is increasing that farmland, and in particular grassland, is important for conserving and increasing biodiversity (Pimentel et al., 1992; Freemark et al., 2002; Daily et al., 2003; Rook and Tallowin, 2003). This could greatly influence conservation efforts as the practice of grass-based farming in the temperate United States expands (Hanson et al., 1998; Ostrom and Jackson-Smith, 2000; Foltz and Lang, 2005). For example, while historical data show the number of Wisconsin dairy farms using managed grazing at around 23% (Kriegl and McNair, 2005), 30% of beginning dairy farmers use managed grazing (Jackson-Smith et al., 1996), indicating that this is a growing trend. While grass-based farming often restores plowed land to its native biome (perennial grassland), most farmers sow non-native, cool-season grasses and forbs (C3 photosynthesis) and manage for low diversity plant assemblages (Paine et al., 1999; Sanderson et al., 2004). There are agronomic tradeoffs to incorporating native warm-season grasses into grazing systems. On the positive side, warm-season grasses have superior forage production during the hot, dry summer months compared to cool-season species. Cool-season grass pastures "slump" in production during these periods which leads to reduced livestock production and performance (Belesky and Fedders, 1995; Casler et al., 1998; Paine et al., 1999). On the other hand, the mechanisms that afford warm-season grasses the ability to remain productive under low resource availability (i.e. greater water and nitrogen use efficiency) also reduce their quality as feed for livestock.

A strong link exists between the attitudes and perceptions of farmers and their conservation actions (Miranowski and Shortle, 1986; Luzar and Diagne, 1999; Maybery et al., 2005), but little is known about farmer attitudes towards native grasses or the extent to which they are using native species in their farming systems. The objectives of this research were to assess 1) the current status of native grass use on Wisconsin grazing farms; and 2) farmer attitudes and perceptions about native grass use in farming systems, and conservation projects in general.

Because the management decisions made by farmers have influence beyond the farm boundary, society is often interested in them (Edwards-Jones, 2006). Understanding farmer attitudes and decision-making processes can help build successful incentive-based environmental programs (Luzar and Diagne, 1999) and can help to structure research and formulate policy aimed at realistic natural resource and agronomic goals. This research provides information that can be used by multiple groups—agronomists, conservationists, ecologists, and policy-makers—towards that end. We also show how classification trees, which are commonly used to analyze complex ecological data, can be used to interpret survey data. In addition, projects that bring a social component to grassland research can be used as a framework to address the call from many stakeholders for more interdisciplinary science. While production-oriented grassland research has contributed greatly to the food needs of an increasing world population (Lemaire et al., 2005), focusing on isolated aspects (e.g., forage production) of pasture ecosystems limits our understanding of the total farm—a system that interacts with both nature and society (Dalgaard et al., 2003; Francis et al., 2003). Therefore, genuine interdisciplinary research of integrated land use and grassland management is needed (Lemaire et al., 2005). Likewise, ecologists and conservationists need to consider human needs for ecosystem services (DeFries et al., 2007) and collaborate with social scientists to address the multiple facets that constitute sustainable land use (Mattison and Norris, 2005).

METHODS

Survey questionnaire

We designed a written questionnaire after holding two focus group discussions with small groups of grass-based farmers to clarify meanings and terminology related to grazing systems, native grasses, and conservation projects. Focus groups are useful to evaluate assumptions about the way people understand terms or concepts that will be used in a survey instrument (Fowler, 1995). From these discussions, we knew clarification of the term 'native grass' was needed. Therefore, the following sentence was included at the beginning of the survey: "*We would like to know if you use native prairie grasses in your grazing system and why or why not. By native prairie grass we mean those species present in the tallgrass prairies that covered many parts of the Midwestern United States before European settlement. These grasses include, but are not limited to, big bluestem (turkey-foot), indiangrass, and switchgrass.*"

Socioeconomic and demographic information was also gathered, including income brackets, farm size, education level, etc. The questionnaire was reviewed by experts in the fields of applied social research, survey methodology, and grass-based farming systems and pilot-tested with five grass-based farmers. In December of 2005, the University of Wisconsin Survey Center (UWSC) was contracted to administer the survey to 800 Wisconsin grass-based farmers (hereafter referred to as farmers). The survey sample list was obtained from the mailing list of Grass Works, Inc., a Wisconsin-based organization of grass-farmers. Respondents were recruited to fill out the questionnaire by a letter that was included with the survey (Appendix 1) and stamped business reply envelope. These items were mailed to the survey participants in February 2006. Farmers were identified by a number on the questionnaire to protect confidentiality. A postcard reminder followed the initial mailing five business days later. A second full mailing was sent out to respondents who had not yet returned a questionnaire approximately three weeks after the initial mailing.

Data analysis

The survey response rate was 56.15%, calculated as the number of returned questionnaires divided by the total number of respondents in the sample minus the number of cases determined to be non-sample, e.g., businesses, [388/(800-109)]. Seventy-seven returned surveys indicated that the respondent was not a grass-based farmer and we did not use these responses in our analyses.

Descriptive statistics were used to assess frequencies of responses. We also combined certain survey questions/statements to create three unweighted indices for overall measures of attitude on conservation projects and perceptions of how native grasses affect the environment and farming production (Table 1). Responses were coded such that higher scores indicated a more positive attitude and lower scores a more negative attitude. We created the summary index variable by adding up each subject's score across the various items. If a respondent had missing data for one of the statements that was used to create an index, their responses were not included in index analyses. The summary score gives a simple index of a farmer's attitude: the higher the score, the more positive the attitude. To test the reliability of the indices we used Cronbach's internal reliability alpha (Table 1), which is a metric of internal consistency based on the average inter-item correlation. If an index did not have an alpha ≥ 0.70, the conventional cut-off level (Austin et al., 2005), it was not used. These data were analyzed with SPSS 11.0.0 (SPSS, Inc., Chicago, IL).

We used classification tree analysis (S-Plus 8.0, Insightful Corporation, Seattle, WA) to determine which variables (index scores, socioeconomic status, farm size, etc.) explained the most variability in farmer interest in using native grasses as part of their grazing systems. Classification trees are a useful nonparametric method for exploring patterns in data that do not fit into the fixed effects of a controlled experiment and that may be shaped strongly by interactions among numerous factors (De'ath and Fabricius, 2000). The predicted variable was farmer response to the statement *I am interested in having native prairie grasses as part of my grazing system*. Farmers were given the option to respond in five ways: strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, and strongly agree. For analysis purposes, responses were grouped into three categories: disagree (strongly disagree + somewhat disagree responses), neither agree nor disagree, and agree (somewhat agree + strongly agree responses). The classification tree was pruned to three nodes to extract the predictor variables that grouped the data into these three responses. Table 2 lists the variables that were used as potential predictors in the classification tree.

We asked farmers to state how important certain factors are when they are considering the implementation of conservation projects in general, not only projects related to native grasses. Many of these factors were included based on focus group discussions with farmers. We assigned numerical values to the responses in the following manner: very unimportant=1, somewhat unimportant=2, somewhat important=3, and very important=4. The mean response (± one standard error) was calculated for a given statement—the higher the score (from 1 to 4), the more important farmers considered this factor.

RESULTS AND DISCUSSION

Native grass use on farms

A small percentage (16.7%) of Wisconsin farmers said they have native grasses on their farm, with median and average areas of 8.09 ha and 10.0 ha (SE ± 1.82), respectively. Native grasses were established for a variety of reasons, including landscaping/beauty (14.7%), Conservation Reserve Program (26.5%), conservation reasons (35.3%), and for livestock forage (41.2%). Of these farmers, 52.9% established the native grasses themselves and less than half received financial (44.4%) or technical (44.8%) aid for the establishment. There are federal and state programs available to help farmers establish native grasses on farms. However, in some cases (e.g., Conservation Reserve Program) farmers do not have the option of grazing or haying those grasslands, which may limit farmer participation (Esseks and Kraft, 1986). In addition, lack of familiarity with native grass establishment assistance (see below) could have contributed to the low percentage of farmers who received aid.

Farmer familiarity with native grasses

Overall, farmers said they are unfamiliar with native grasses (Table 3). Only 16.3% reported that they find it easy to identify native prairie grass species, and most are unaware of aid and seed sources for establishment. Very few know someone who uses native grasses in their grazed pastures. Our findings are similar to surveys in the midwestern and southeastern regions of the United States where farmers said they were unfamiliar with conservation techniques (Integrated Pest Management) and native flora and fauna (Blesh and Barrett, 2006). Lack of knowledge can be a major limiting factor for adoption of conservation or restoration projects (Traore et al., 1998; Luzar and Diagne, 1999; Pejchar and Press, 2006), and farmers have indicated that availability of information is important to them for successful implementation of a conservation project (Batte et al., 1990). Our results indicate a need for increased education and extension efforts on native grass establishment and identification.

Farmer interest in native grasses

Thirty-five percent of farmers said they are interested in using native prairie grasses in their grazing systems and 48% would use them for forage (Fig. 1). Given that most farmers reported themselves to be largely unfamiliar with native grasses, this is a surprisingly large number of farmers interested in using native grasses. Smaller percentages of farmers said they are not interested in native grasses in their grazing system and would not use them as forage. A fairly large percentage is not sure about the use of native grasses for their grazing system or as forage. This could be a reflection of the unfamiliarity farmers reported with native grasses.

Classification tree results showed that the first, and most important, predictor of responses to the statement *I am interested in having native prairie grasses as part of my grazing system* was index 2 scores—farmer perception of how native grasses affect the environment (Fig. 2). If farmers had high index scores, indicating a positive perception of native grass effects on the environment, they were more likely to be interested in using native grasses. If they had low index scores, another predictor—index 3, perception of how native grasses affect farm production—separated those farmers into two groups: those who are not interested in and those who are unsure about using native grasses. Farmers who perceive that native grasses could positively affect farming production are unsure about the use of native grasses, while farmers who think native grasses could negatively affect production are not interested in them. The misclassification rate for the classification tree was 38.7%.

Many struggle to stay viable in the farming profession (Blesh and Barrett, 2006), and while grazing farms can be profitable (Frank et al., 1995), there can be economic barriers to adoption and use of conservation projects (Napier, 1998). Our classification results indicate that economics are not the main factor driving farmer attitudes towards native grass use—interest in the environment is. Similar results were found in Iowa where farmers indicated they place more importance on ecological and social goals than production for desired future landscapes (Santelmann et al., 2004).

Farmer perceptions of native grasses

We asked a series of questions to assess farmer perceptions of how native grasses could affect various aspects of farming life, including effects on the environment, production, management, and society (Table 4). Many farmers think it is likely that there are environmental benefits to native grasses, including improved soil conditions, environmental conditions, and wildlife habitat. However, many perceive that native grasses could lower forage production and quality. That could explain why only 41.2% of farmers who established native grasses did so for use as forage. Native grasses generally have lower forage quality than introduced species (Balasko and Nelson, 2003), but improved varieties of native grasses are being developed (Mitchell et al., 2005). However, there are equivocal results on overall grassland production and cattle weight gain when warm-season pastures are part of a grazing system (Belesky and Fedders, 1995; Smart et al., 1995; Reich et al., 2001; Moore et al., 2004). The unfamiliarity farmers reported with native grasses may well be a reflection of the research still needed in this area.

Forty-five percent of farmers believe native grasses could result in better forage yields under adverse weather conditions. As mentioned previously, most temperate pastures are sown to exotic cool-season perennial grasses and legumes that "slump" in production in late summer. The photosynthetic pathway of warm-season grasses affords them higher water use efficiency and therefore less water stress during drier periods (Lambers et al., 1998), resulting in greater production in hot, dry conditions compared to cool-season grasses. With increased concern on how climate change will affect agricultural production, native warm-season grasses could provide increased flexibility in farming management (Moore et al., 2004).

Longer establishment time and financial risk are considered to be likely results of having native grasses by 40.2% and 64.0% of farmers, respectively. Changing management appears risky to many farmers as they have little room for economic error (Blesh and Barrett, 2006). Management of native grasses differs from cool-season pastures (Anderson, 2000) and may be unfamiliar to farmers. Indeed, establishment of native warm-season grasses can be difficult (Jackson, 1999; Waldron et al., 2005) and more research is needed on effective establishment techniques. Much could be learned from the farmers who have established native grasses successfully into their farming systems.

Over one third of farmers believe that including native grasses could improve society's perception of farming and 20.6% believe that native grasses could improve their quality of life. However, farmers consistently reported much uncertainty on how native grasses could affect various aspects of farming life, with large percentages reporting *neither likely nor unlikely* for many statements (Table 4). Farmers may believe that native grasses will not affect these aspects of farming life, or these results could be a reflection of the unfamiliarity farmers said they have with native grasses, and/or the equivocal scientific results on native warm-season grasses. When perceived risks and benefits of a conservation project are not clear, there is more likely to be resistance to its implementation (Kabii and Horwitz, 2006).

Factors considered important when implementing conservation projects

Identifying reasons for, or predicting, farmer adoption of conservation projects or sustainable agriculture practices can be difficult (Napier et al., 2000; Napier and Tucker, 2001; Jacobson et al., 2003; Bell, 2004), and our results reflect that complexity. Many factors were listed as important to farmers when considering the implementation of conservation projects (Table 5). Both financial and environmental considerations were ranked as highly important to farmers. Among the highest factors were the potential of projects to protect the environment and conserve/improve resources. Most landowners who establish conservation practices do so because they value nature (Pejchar and Press, 2006). The results from Table 5 complement the classification tree findings which showed the importance farmers place on the environment when considering native grasses. Economics were ranked as highly important as well, and conservation programming should continue to look at conservation projects that will produce profits for land owners in the short-term (Napier et al., 2000). Desire to improve their public image and peer pressure can guide farming practices (Carolan, 2005; Michel-Guillou and Moser, 2006), but among the lowest ranked factors for farmers was the reaction of others, including neighbors and potential future buyers of the land.

CONCLUDING REMARKS

Our results indicate that many farmers are interested in using native grasses in their grazing systems, but are unfamiliar with how to proceed. Furthermore, we show how environmental considerations are equally, or more, important than financial/production considerations for farmers when contemplating the use of native grasses or conservation projects in general. This shows that the financial bottom line is not the main driver of farmer conservation actions. While many farmers believe native grasses could improve the environment, many also think they would negatively affect forage production and quality, except in adverse weather conditions.

Understanding farmer attitudes at the local level should help to build successful, incentive-based conservation programs and inform research projects and policy initiatives aimed at realistic natural resource and agronomic goals. By using an interdisciplinary approach, we were able to broaden the scope of grassland research and provide valuable information to agronomy researchers and extensionists, conservationists, and policy-makers. Specifically, our results highlight the need for these stakeholders to:

- Learn from farmers already using native grasses in their farming systems.
- Improve our understanding of native grass effects on both the environment and agronomic production.
- Augment research on establishment and management of native grasses in grazing systems.
- Enhance education and extension efforts to farmers about native grass identification, establishment techniques, and management issues.
- Formulate projects and policy that help farmers incorporate native grasses into their farming systems and consider the perceived risks farmers have of such projects.

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TABLES

TABLE 1. Indices of farmer attitudes towards native grasses and conservation projects created from survey statements. The index was formed by summing each survey participant's scores from the response scales[1]. Responses were coded such that 1 always represented a negative attitude and 5 a positive attitude; therefore, higher index scores reflect more positive attitudes or beliefs in the topic and vice versa. The possible numerical range of each index is indicated in the last column. Each survey statement contributed equally to the calculation of the given index.

Index	Survey statements forming index	Internal reliability of index[2]	Numerical range of index
1. Attitude towards conservation projects	Having conservation projects on my farm is important to me.[a]	0.746	5–25
	I spend/have spent a considerable amount of money on implementing and maintaining conservation projects on my farm.[a]		
	I am satisfied with my current conservation projects.[a]		
	I want to have more conservation projects on my farm.[a]		
	I think my current conservation projects benefit the environment.[a]		
2. Perception of how native grasses affect the environment	I think native prairie grasses could benefit the environment[a]	0.887	4–20
	How likely it is that native grasses in grazed pastures will result in[b]:		
	Improved soil conditions		
	Improved environmental conditions		
	Improved wildlife habitat		
3. Perception of how native grasses affect farm production	How likely it is that native grasses in grazed pastures will result in[b]:	0.763	9–45
	Lower overall pasture production		
	Higher overall pasture production		
	Better forage yields under adverse weather conditions		
	Lower forage quality		
	Higher forage quality		
	Healthier livestock		
	More labor requirements		
	More financial risk		
	A longer establishment period		

Notes: [1]Sum of responses, 1-5 from one of two response scales: [a]strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, or strongly agree; [b]very unlikely, somewhat unlikely, neither likely nor unlikely, somewhat likely, or very likely; [2]Cronbach's alpha.

TABLE 2. Variables used in the classification tree as potential predictors of responses to the statement *I am interested in having native prairie grasses as part of my grazing system*.

Variable	Type	Notes
Index 1: Attitude towards conservation projects	Numerical	See Table 1 for survey statements that are part of this index
Index 2: Perception of how native grasses affect the environment	Numerical	See Table 1 for survey statements that are part of this index
Index 3: Perception of how native grasses affect farm production	Numerical	See Table 1 for survey statements that are part of this index
Acres owned	Numerical	
Acres rented	Numerical	
Acres used for grazing	Numerical	For both rotational & continuous grazing
Location of farm	Categorical	One of three climate zones in WI (north, south transition zone)
Number of dairy cattle	Numerical	Includes heifers & young stock
Number of beef cattle	Numerical	Includes young stock
Number of sheep	Numerical	
Income bracket	Categorical	One of 10 categories, ranging from <$5000 to >$200,000
% of income from farm	Categorical	One of 5 categories, ranging from <10% to 76–100%
Age of farmer	Numerical	
Last grade in school completed	Categorical	
Years of farming	Numerical	
Future plans for the farm	Categorical	One of 7 responses, including land operated by children, land will be sold for development, future unknown, etc.
Belong to any environmental organizations	Categorical	Yes or no
Belong to any agricultural organizations	Categorical	Yes or no
Knows someone using native grasses in pastures	Categorical	Yes or no
Aware of programs or aid to help with cost of planting native grasses on the farm	Categorical	Yes or no
Would need technical assistance to plant native grasses on the farm	Categorical	Yes or no
Knows where native grass seed available to buy	Categorical	Yes or no

1

TABLE 3. Farmer responses to survey statements on familiarity of native grasses and their establishment.

	Farmer response		
Survey statement	Yes (%)	No (%)	
Knows someone using native grasses in grazed pastures	13.3	86.7	
Is aware of programs/aid to help with the cost of establishing native grasses	13.9	86.1	
Would need technical assistance to establish native grasses	67.5	32.5	
Knows where native grass seed is available to buy	35.0	65.0	
	Disagree[1] (%)	Neither agree nor disagree (%)	Agree[2] (%)
Finds it easy to identify native grass species	52.7	26.4	16.3

Notes: [1]Sum of strongly disagree & somewhat disagree responses;[2]sum of strongly agree and somewhat agree responses.

TABLE 4. Farmer responses to survey statements on how native grasses in grazed pastures could affect various aspects of farming life.

Survey statement: *Having native grasses in my grazed pastures will result in:*	Farmer response		
	Unlikely[1] (%)	Neither likely nor unlikely (%)	Likely[2] (%)
Improved soil conditions	12.3	46.2	41.3
Improved environmental conditions	9.8	44.4	45.8
Improved wildlife habitat	7.0	30.4	62.6
Lower overall pasture production	12.4	43.0	44.7
Higher overall pasture production	41	46.3	12.7
Better forage yields under adverse weather conditions	12.4	42.3	45.4
Lower forage quality	8.9	45.6	45.6
Higher forage quality	40.4	49.1	10.5
Healthier livestock	14.5	65.5	20.1
More labor requirements	22.0	54.2	23.8
More financial risk	12.4	47.5	40.2
A longer establishment period	3.8	32.2	64.0
Better quality of life for me and my family	18.5	60.8	20.6
Improved perception of my farming practices from society	16.1	47.9	36.0

Notes: [1]Combination of somewhat unlikely and very unlikely responses;[2]combination of somewhat likely and very likely responses.

TABLE 5. Farmer responses to how important the listed factors are when considering the implementation of conservation projects. Overall mean importance[1] and standard error (SE) are reported. Higher mean importance scores indicate farmers placed higher importance on that factor. Responses are listed from highest to lowest mean importance scores.

	Farmer response				
Survey statement	Very unimportant (%)	Somewhat unimportant (%)	Somewhat important (%)	Very important (%)	Mean importance[1] (± one SE)
Value[2]	*1*	*2*	*3*	*4*	
Potential of projects to protect the environment	0.7	3.7	37.5	58.2	3.53 (0.035)
Potential to improve quality of life	0.3	4.7	36.2	58.7	3.53 (0.035)
Potential of projects to conserve/ improve resources	0.7	4.3	42.2	52.8	3.47 (0.035)
Cost to implement conservation projects	2.0	4.7	38.9	54.5	3.46 (0.039)
Potential of projects to ease labor in working the land	1.0	8.3	38.2	52.5	3.42 (0.042)
Cost to maintain conservation projects	1.3	7.0	40.7	51.0	3.41 (0.039)
Availability of information on the conservation projects	1.7	10.6	52.2	35.5	3.22 (0.040)
Restrictions agencies impose as the price of receiving cost-sharing	5.0	14.1	39.3	41.6	3.17 (0.050)
Potential of projects to improve wildlife habitat	1.0	16.7	47.7	34.7	3.16 (0.042)
Potential of projects to beautify farm	2.3	13.1	51.0	33.6	3.16 (0.042)
Demonstrated profitability of conservation projects	2.7	13.8	50	33.6	3.14 (0.043)
Ability to implement projects with little outside assistance	1.3	15.9	50.8	31.9	3.13 (0.041)
Amount of government cost-sharing available for projects	7.7	12.7	42.8	36.8	3.09 (0.052)
Amount of time to maintain conservation projects	3.3	12.7	56.3	27.7	3.08 (0.042)
Potential loss of production associated with adopting conservation projects	4.0	19.9	46.5	29.6	3.02 (0.047)
Amount of time to implement conservation projects	3.0	16.3	58.8	21.9	3.0 (0.041)
Amount of government technical assistance available for projects	8.4	14.4	46.8	30.4	2.99 (0.051)

The disruption in farming operations in order to implement the conservation projects	4.0	22.3	47.3	26.3	2.96 (0.046)
Necessity to acquire new skills to implement and maintain the conservation projects	7.0	18.9	56.8	17.3	2.84 (0.045)
The need to work with any agency personnel to implement projects	8.7	36.5	42.1	12.7	2.59 (0.047)
Reaction of future buyers/renters of land	17.6	28.6	33.9	19.9	2.56 (0.058)
Reaction of neighbors	28.6	31.6	29.9	10.0	2.21 (0.056)

Notes: [1]Average of responses based on the numerical value[2] given to the following responses: very unimportant=1, somewhat unimportant=2, somewhat important=3, and very important=4.

FIGURES

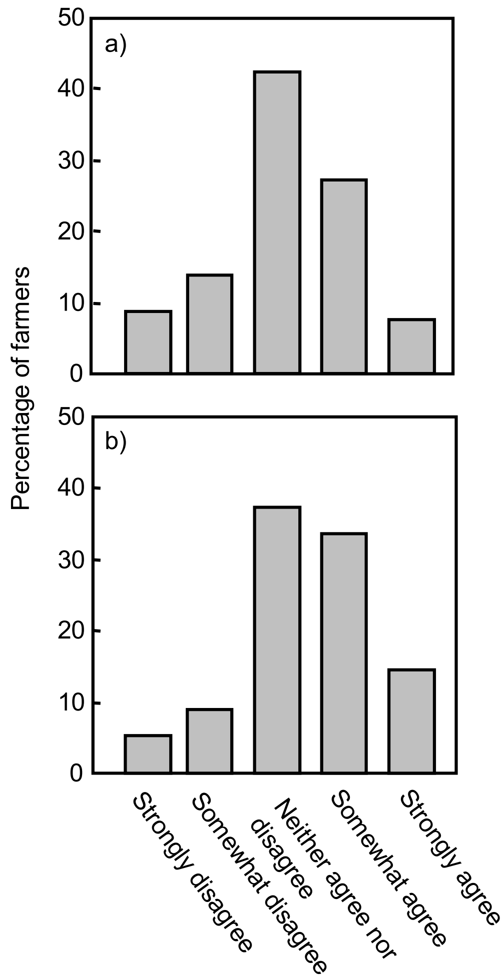

FIGURE 1. Farmer responses (%) to the statements a) I am interested in having native prairie grasses as part of my grazing system and b) I would use native prairie grasses for livestock forage.

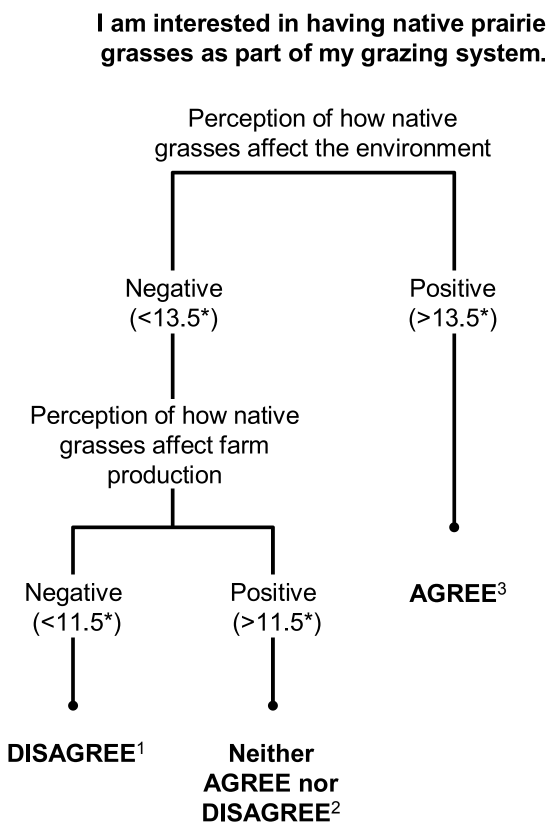

FIGURE 2. Classification tree predicting response (agree, neither agree nor disagree, or disagree) to the statement *I am interested in having native prairie grasses as part of my grazing system.* The first, and most important, response predictor was farmer perception of how native grasses affect the environment. If farmers perceived that native grasses are good for the environment, they were most likely to be interested in using native grasses. If they perceived native grasses are not good for the environment, another predictor—perception of how native grasses affect farm production—separated those farmers into those who are not interested or were unsure about using native grasses. The total misclassification rate for the tree was 38.7%. *Values from the index range (see Table 1). [1]Node with n=28; 71% of these classified as disagree. [2]Node with n=77; 62% of these classified as neither agree nor disagree. [3]Node with n=125; 58% these classified as agree.

Chapter 2. Rotational grazing and carbon addition limit establishment of native C4 grasses into existing C3 pastures

ABSTRACT

Incorporating native warm-season (C4) grasses into pastures dominated by cool-season (C3) grasses could provide ecological and agronomic benefits, such as increased productivity and carbon sequestration, resistance to weed invasion, greater landscape diversity, and improved wildlife habitat. We conducted a field experiment testing combinations of disturbance (burning and grazing), soil amendment (ambient, nitrogen, and carbon), and seeding time (fall 2003 and spring 2004) aimed at promoting establishment of native C4 grasses into a pasture dominated by introduced C3 grasses, legumes, and forbs. We examined whether native grasses recruited within treatments and if so, at what rate over a three year period (2005 through 2007). Native grasses did not recruit where nitrogen was applied. Recruitment was greater under burning than grazing and slower with carbon addition compared to ambient soil conditions, but did not differ between seeding times. Regression tree analyses showed that the best predictor of native grass density in 2006 and 2007 was belowground net primary production, which was greater under burned plots but did not differ between carbon and ambient treatments. Carbon addition significantly reduced net nitrogen mineralization, and summer net mineralization rates were positively correlated with aboveground net primary production, suggesting that the carbon treatment had some negative effect on pasture production as well as native grass growth. This research informs management for farmers who want to incorporate native grasses into their grazing systems without complete pasture renovation. While native grasses became established where carbon was applied and grazing occurred, better recruitment was observed under burning and ambient soil conditions.

Burning would require the farmer to remove some land from production in the fall to accumulate fuel-load and in early spring when grazing would be deferred while native grasses established. Farmers may be willing to trade this forage production for a successful establishment of native grasses, especially since it would allow them to avoid complete pasture renovation. More broadly, this research informs efforts that attempt to integrate agricultural and restoration goals in the landscape, and conservation and restoration theory that seeks to augment grassland plant diversity via seed addition into existing grasslands.

INTRODUCTION

Increasing the diversity of managed grasslands may have agronomic and ecological benefits, such as greater productivity (Tilman et al., 1996; Hector et al., 1999), stability (Minns et al., 2001; Moore et al., 2004), nutrient retention (Tilman et al., 1996), and resistance to weed invasions (Tracy and Sanderson, 2004; Renne et al., 2006). In particular, the coexistence of exotic cool-season (C3) and native warm-season (C4) grasses has been promoted both as a realistic prairie restoration goal (Wilson and Partel, 2003) and an agronomic tool for grass-based farmers. More tallgrass prairie, dominated by C4 grasses, has been lost than any other terrestrial ecosystem (Samson and Knopf, 1994) and efforts to restore this community are significant. Land managers plant native tallgrass prairie species to increase carbon sequestration (Tufekcioglu et al., 1998), improve habitat for birds (Giuliano and Daves, 2002), and/or promote diversity in the landscape (Nelson and Burns, 2006).

In many temperate areas of the United States, species-poor annual cropping systems are being converted to more diverse perennial grasslands for managed grazing (Hanson et al., 1998; Ostrom and Jackson-Smith, 2000; Foltz and Lang, 2005). Typically farmers establish these pastures with non-native C3 grasses and manage for plant assemblages that include one to five species (Sanderson et al., 2004). Combining C3 and C4 grasses has been promoted as a way to improve the distribution and quantity of forage production for grass-based farmers (Belesky and Fedders, 1995; Moore et al., 2004; Springer et al., 2007). Studies using both simulations and field data have reported greater production from C3-C4 mixtures than grasslands with C3 grasses only (Albertson and Weaver, 1944; Lorenz and Rogler, 1972; Seastedt et al., 1994). Belesky and Fedders (1995) found that while there were fewer growing days for C4 compared to C3 grasses in a temperate environment, dry matter yields of C4 grasses were greater than or equal to the yields of identically managed C3 grasses.

Studies investigating the coexistence of C3 and C4 grasses for agronomic purposes have 1) used monocultures of C3 and C4 pastures in a system, i.e., sequential grazing of pastures (Jung et al., 1985; Belesky and Fedders, 1995; Smart et al., 1995; Moore et al., 2004), 2) completely renovated land and simultaneously seeded C3 and C4 species together (Posler et al., 1993; Smart et al., 1995; Waldron et al., 2005), or 3) transplanted seedlings of C3 and C4 grasses into renovated land (Springer et al., 2001; Springer et al., 2007), which may be cost prohibitive for farmers. Herbicide use has been effective in C4 grass establishment (Samson and Moser, 1982), but organic farmers and others may be opposed to herbicide use and leaving the existing plant community in place may be preferable to complete pasture renovation (Williams et al., 2007). In addition, pasture renovation can be expensive, results in land taken out of production for months, and may increase soil erosion and carbon loss. Achieving coexistence of C3 and C4 grasses in the same area has proven difficult, and past attempts to directly seed species into established pastures have resulted in mixed results (Bryan et al., 1984; Jackson, 1999).

We conducted a field experiment to test management techniques for establishing native C4 grasses in either the spring or fall into an existing C3 pasture. We drill-seeded C4 grasses into a pasture and then applied combinations of disturbance (grazing and burning) and soil amendment (carbon, nitrogen, and ambient) treatments aimed at manipulating plant-plant and plant-herbivore interactions to promote establishment of C4 grasses in this competitive matrix. We considered burned plots as our control as other work has shown that burning promotes C4 grasses. We were interested in testing whether grazing could substitute for burning, as the objective of this work was to incorporate native grasses into a production-oriented agricultural system. First, we hypothesized that C4 grass recruitment would occur under both disturbances, but be greater under burning than grazing. Cool-season grasses have been bred to grow tall as fast as possible. A dense, monotypic sward is usually the agronomic goal for these pastures (Paine et al. 1999), likely making competition for light the main limiting factor. Reducing existing vegetation cover is important when sowing desirable species into existing grasslands (Lawson et al., 2004; Martin and Wilsey, 2006). Disturbances such as grazing and burning may suppress the C3 species until the slower growing C4 grasses can build enough aboveground biomass to effectively compete for belowground resources. Research conducted in the western tallgrass prairie indicates that frequent spring burning favors C4 grasses (Knapp and Medina, 1999) while grazing reduces their dominance (Collins, 1987). Cattle grazing can be an effective tool for prairie restoration (Helzer and Steuter, 2005), but an understanding of how it affects C4 grasses sown into C3 pastures is lacking.

Second, we hypothesized that C4 grass recruitment would be greater under carbon addition than nitrogen addition and ambient soil conditions. Tilman's (1985) resource-ratio hypothesis predicts that if slower growing, more resource efficient C4 grasses can become established, they should ultimately prevail if the resource for which competition is strongest is limiting, i.e., nitrogen in most temperate grasslands (Knapp and Seastedt, 1986; Burke et al., 1997). Differences in nitrogen availability have been shown to alter competitive interactions and outcomes in nitrogen-limited ecosystems (Turner and Knapp, 1996; Turner et al., 1997). Carbon addition—in the form of sugar, sawdust or wood chips—has been observed to immobilize soil nitrogen in grasslands making it less available for plant uptake (Wilson and Gerry, 1995;

Morghan and Seastedt, 1999; Blumenthal et al., 2003). We expected lower soil nitrogen levels to benefit the seeded native grasses—not because they are native species, but as a result of their photosynthetic pathway (C4). Warm-season grasses are more nutrient use efficient (Long, 1999), and decreased amounts of available nitrogen should give them a competitive advantage relative to the existing C3 grass species. Nitrogen fertilization was included as a treatment as it is a common practice to promote productivity in temperate pastures.

This research provides information for farmers who want to incorporate native grasses into their pastures without complete renovation. More broadly, this research should inform efforts that attempt to integrate agricultural and restoration goals in the landscape and conservation and restoration theory that seeks to augment grassland plant diversity via seed addition to existing grasslands.

METHODS

Study site

This study occurred on a farm in southwestern Wisconsin (43.175 N, -90.067 W). The climate is temperate-continental with cold winters and warm summers. Average temperatures range from -7 ^{o}C in January to 20 ^{o}C in July. Temperatures during the study period (2004 through 2007) were close to these averages. Average annual precipitation is ~850 mm, with about two-thirds of the annual precipitation falling during the growing season, roughly April to October. Yearly total precipitation amounts for 2004 through 2007 were 872, 646, 1141 and 1396 mm, respectively. The soil of the experiment area was classified as Fayette silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs) and the area had a 12 to 20% slope. The farm produced beef cattle (*Bos taurus*) using a management-intensive rotational system—this is short duration (<12 hours to three days) grazing with high stocking densities and two to five week rest periods (Paine et al., 1999). The plots in the experiment area all had the same management history—rotational grazing for more than 15 years—and were dominated by non-native C3 grasses.

Treatments and data collection

Fall (November 2003) and spring (May 2004) native grass seeding occurred by drill-seeding three native C4 species—*Andropogon gerardii* Vitman (big bluestem), *Panicum virgatum* L. (switchgrass), and *Sorghastrum nutans* (L.) Nash (indiangrass)—at a rate of ~1.0 g m^{-2} with a seed mix comprised of 70% big bluestem, 15% indiangrass, and 15% switchgrass into an existing 1.5-ha cool-season pasture. Local ecotype native grass seed collected from Wisconsin prairie sites was used.

Disturbance and soil amendment treatments were applied after native grass seeding from 2004 through 2007 in a hierarchical design (split-split-split) using three 0.5-ha pastures as experimental blocks (Fig. 1). Disturbance treatments (graze or burn) were randomly applied to one-half of each block. Each disturbance level was randomly split into a fall (2003) or spring (2004) seeding of native grasses. A further split of each seeding time treatment level resulted in three subplots randomly assigned to one of three soil amendment levels: ambient (N0), nitrogen fertilization (+N), or carbon application in the form of sawdust (+C). Grazing treatments followed the rotational grazing system and were initiated in early June of 2004. The burn treatment occurred in April of 2005 through 2007 and removed 100% of the aboveground vegetation. These plots were not defoliated for the remainder of the year. The +C plots received sawdust in a split application (June and August) at a rate of 1.2 kg sawdust m^{-2} y^{-1} in 2004 and 2005. The sawdust came from several Wisconsin sawmills, was finely textured and dry, and had a carbon:nitrogen ratio of 174. The +N plots received 180 kg NH_4NO_3 ha^{-1} y^{-1} applied in a split application (June and August) in 2004, 2005, and 2007. The ambient treatment did not receive soil amendments. This experimental design resulted in three replicates (one per block) for each treatment combination. In 2007, half of the burned plots within each block were removed from the experiment to be used for other purposes, resulting in 24 experimental units for that year.

Native grass density was estimated in late August/early September from 2005 through 2007 by counting the number of native grass tillers in a 1 m^2 quadrat placed every 10 meters along the experimental unit. Totals from these plots were averaged to calculate density as native grass tiller m^{-2}.

Ancillary data was collected from 2004 through 2006 to help explain treatment effects on native grass recruitment. We were especially interested in how the carbon treatment affected net nitrogen mineralization rates, as nitrogen immobilization has been the proposed mechanism for its use as a prairie restoration tool. In 2004, we estimated aboveground net primary production (ANPP) by monthly clipping biomass from two 10 × 50 cm quadrats randomly placed in each experimental unit. In 2005 and 2006, we calculated ANPP from an allometric relationship with leaf area index (LAI, r^2=0.84), which was calculated from intercepted photosynthetically active radiation (PAR) readings (Accupar LP-80, Decagon, Inc., Pullman, WA) made above and below the leaf canopy at four points along each experimental unit. For each experimental unit, biomass weights (2004) and LAI readings (2005 and 2006) were averaged to estimate biomass per experimental unit. Clippings and LAI readings were taken monthly for plots that were burned and before and after each grazing event for grazed plots and summed to calculate ANPP. Belowground net primary production (BNPP) was estimated with root ingrowth cores (Bledsoe et al. 1999) where two soil cores per experimental unit were removed prior to the growing season and sieved. The cores were 5 cm in diameter and taken to a depth of 15 cm. The soil was returned to cores of the same dimensions fashioned by 2-mm plastic mesh material, inserted back into the original hole, and harvested at year's end. Roots were washed, dried to constant weight at 60° C and weighed.

Soil samples were collected in the spring (2004 through 2006), summer (2005 and 2006) and fall (2004 through 2006) for gravimetric water content (GWC), net nitrogen mineralization, soil texture, and percent carbon and nitrogen. Soil cores were 2.5 cm in diameter and taken to a 10 cm depth at 12 locations stratified randomly along each experimental unit. For each experimental unit, these cores were aggregated and sieved (2 mm) to remove vegetative and mineral materials, then subdivided to be used for different analyses. Approximately 15 grams of soil was weighed, dried at 105° C to constant weight, and reweighed to calculate GWC. We used 2M KCl extractions with an aerobic incubation period of seven days to measure net nitrogen mineralization (Robertson et al. 1999). In 2004 and 2005, a flow injection analysis using a Lachat QuikChem (Lachat Instruments, Loveland, CO) was used to determine NH_4^+ and NO_3^- values. For samples collected in 2006 we used an adapted microplate spectrophotomer method (Rhine et al., 1998) for this analysis. Soil texture was determined from fall 2005 soils using the hydrometer method (Elliot et al., 1999). Soil nitrogen and carbon percentages were determined using an automated elemental analyzer (Flash EA 1112, CE Elantech, Lakewood, NJ) after soils were dried at 60° C and pulverized.

Plant species cover was estimated twice annually (spring and fall) from 2004 through 2006 with the line-point method where the first interception of a sharpened rod with any part of herbaceous vegetation was recorded for 10 hits along a 10 × 50 cm quadrat (Heady et al., 1959). This was repeated every 10 m along a 50-m transect for a total of 50 hits per experimental unit.

Statistical analyses

A two-phase approach was used to determine treatment effects on native grasses. First, we assessed whether native grasses recruited. If they did, we sought to determine whether the rate of recruitment was affected by treatment level. The threshold criteria for recruitment was whether an average of one tiller m^{-2} was found in a plot by 2007. Experimental units with density levels less than this were considered agronomic or restoration failures. Plots of means and standard errors were used to filter plots with and without significant recruitment. After eliminating all experimental units from the single treatment where native grasses did not recruit (nitrogen addition), we used analysis of covariance (ANCOVA) in a linear mixed-effects (LME) modeling framework that allowed us to evaluate how native grass recruitment occurred under each treatment combination. Native grass tiller density was transformed ($\log[\sqrt{y} + 1]$) to meet the assumptions of normality and regressed on year as an integer variable with treatment combinations as grouping factors. We used model simplification based on Akaike Information Criterion (AIC) and the restricted maximum likelihood algorithm (REML) to estimate random effects, variance-covariance structure, and fixed effects. Model selection procedures followed Crawley (2002), where terms were dropped and the subsequent model compared to the more complex model with likelihood ratio tests. If models were significantly different (P<0.05), the model with the lower AIC was chosen, otherwise we continued model selection with the more parsimonious model. The variance-covariance structure was determined by fitting saturated models with the autoregressive function (AR1) that fit a parameter describing residuals whose correlation structure declines exponentially with time. We also tested for heteroscedasticity by fitting separate error terms for each treatment level combination. Model simplification for the fixed effects structure started with a fully parameterized model with each level of disturbance, seeding time, and soil amendment fit with a separate slope and intercept. This model was tested against reduced models where slope parameters factor levels were removed. If separate slopes were needed for treatment levels, it would signify that native grasses were recruiting at different rates per treatment level. To test for non-linear components in the model, the square power of the covariate year was used and tested against a model without it. Plots of residuals and qqnorm plots were assessed for normality.

For the second phase of analysis, we used regression trees to determine which environmental variables explained the most deviance in native tiller density in 2006 and 2007 (transformed as mentioned above). Regression trees are a useful nonparametric method for exploring patterns in data (De'ath and Fabricius, 2000; Crawley, 2002). The environmental variables used in the regression trees are listed in Table 1. Because ancillary data was not collected in 2007, the same environmental variables were used for both the 2006 and 2007 regression trees. Trees were pruned by calculating the deviance explained by each predictor variable. If a split did not contribute to 10% or more of the deviance explained in the tree it was removed.

To help explain the results, means and standard errors of net nitrogen mineralization, BNPP, and ANPP were observed. We also correlated net nitrogen mineralization to ANPP using linear regressions with ANPP as a function of 1) spring (2004 through 2006) and 2) summer (2005 and 2006) mineralization rates. S-Plus 8.0 (Insightful Corporation, Seattle, WA) was used for all data analyses.

RESULTS

Nitrogen addition plots were under the threshold level of one tiller m^{-2} for each level of treatment combination and therefore not used in ANCOVA or regression tree analyses. Overall, tiller averages and standard errors for native grasses in +N plots from 2005–2007 were 0.11 (+/- 0.05), 0.21 (+/- 0.14), and 0.50 (+/- 0.33) tillers m^{-2} respectively. Native grass averages for all other treatment levels were greater than or equal to one tiller m^{-2}. Average ANPP under nitrogen addition was greater than or equal to carbon and ambient plots in 2004 through 2006 (Fig. 2).

Model selection resulted in separate slopes for both disturbance and soil amendment levels, but not for seeding time (Table 2). S-Plus gives ANCOVA output in terms of adjustments to the grand slope and intercept that are set for a given level of each factor. The third column in Table 2 denotes the direction and magnitude of how a factor level's slope differed from that of the grand slope. There was a larger slope for burned and N0 plots compared to grazed and +C plots (Table 2), i.e., native grasses recruited faster under a) burning than grazing and b) N0 than +C plots (Fig. 3).

Regression tree analyses showed the best predictor of both 2006 and 2007 tiller abundance to be 2006 BNPP: plots with greater BNPP (>314.49 g m^{-2} for 2006 and >355.23 g m^{-}

^{2} for 2007) had higher native tiller density. The regression trees explained 72.5% and 77.9% of the deviance in 2006 and 2007 tiller density, respectively. Plots that were burned had higher 2006 BNPP than grazed plots while there was no separation in BNPP between +C and N0 plots (Fig 4). To explore why +C plots were establishing at a slower rate than N0 plots, we looked at means and standard errors of spring and summer net nitrogen mineralization and ANPP. Overall, +C plots had lower mineralization rates than N0 plots, including periods of N immobilization (Fig. 5). In some periods, ANPP was lower where carbon was applied, but this was not consistent from 2004 through 2006 (Fig. 2). There was, however, a significant but weak (r^2=0.11) positive relationship between summer net nitrogen mineralization rates and ANPP (P=0.02). There was no correlation between spring mineralization rates and ANPP (P=0.23).

DISCUSSION

Faster recruitment under burning than rotational grazing

Many studies have documented increased C4 grass abundance under burning (Collins et al., 1998a; Prober et al., 2005; Brudvig et al., 2007; MacDonald et al., 2007). Fire affects ecosystems via changes in NPP, species dominance, soil moisture, nitrogen availability, and hydrological output (Collins et al., 1998b), which can affect plant-plant interactions. Out of the many variables included in the regression tree analysis, the best predictor of 2006 and 2007 native grass tiller density was 2006 BNPP, which was greater in burned plots. Grass root production can increase (Ojima et al., 1994; Rice et al., 1998) or remain constant (Benning and Seastedt, 1997) in response to burning, and there is no general relationship between grazing and changes in root mass (Milchunas and Lauenroth, 1993; Bardgett and Wardle, 2003).

Reducing the existing biomass in grasslands by grazing or clipping can enhance the survival of sown species (Hutchings and Booth, 1996; Lawson et al., 2004; Martin and Wilsey, 2006). Our grazing treatment—which was high intensity, short duration—reduced biomass at quasi-regular intervals, but resulted in low levels of native grass recruitment compared to the burn treatment. Less intense (i.e., >10 cm clipping height) and/or less frequent (i.e., >40 day recovery period) defoliation may promote persistence of big bluestem (Mousel et al., 2003; Mousel et al., 2005). Recommendations for C4 pastures include delayed cutting and leaving plant residual of 10 to 15 cm (Sanderson, 2000). However, growth analyses of C4 and C3 grasses show that C4 grasses have the ability to be highly productive in a cool-temperate environment under frequent defoliation, and certain C3 and C4 grasses appear to be suitable for use in mixtures (Belesky and Fedders, 1995). Because of the need to reduce aboveground competition for the seeded species, delayed defoliation may not be feasible during the establishment phase of C4 grasses into existing C3 pastures.

Burned plots were not defoliated after the burn treatment was applied in early spring, allowing the native plants to set seed. This could have contributed to better establishment under this treatment, and future research is needed to quantify the amount of recruitment after the initial seeding that is due to the seed production of established native grasses. Those results could lead to grazing management recommendations that allow for seed addition to the pasture via established plants.

Carbon limits recruitment

In general, carbon addition to grasslands has resulted in suppression of non-native plants, but the response of native species has been equivocal (Wilson and Gerry, 1995; Morghan and

Seastedt, 1999; Reever Morghan and Seastedt, 1999; Baer et al., 2003; Blumenthal et al., 2003; Averett et al., 2004; Corbin and D'Antonio, 2004; Vinton and Goergen, 2006; Bleier and Jackson, 2007) . The general effect of carbon is to limit plant growth leading to reduced cover and competition for light (Blumenthal et al., 2003), and when used as a restoration tool, it is hoped that this will enhance the growth of the introduced native species. However, there may be a point at which native plant growth is also limited. In our experiment, the carbon application did not consistently limit productivity compared to ambient conditions, although in 2005 and 2006 it was lower in burned and grazed plots, respectively. There was, however, a positive correlation between summer net nitrogen mineralization and ANPP, and net mineralization rates for +C plots were lower. This indicates that part of mechanism underlying lower native grass recruitment may have been reduced plant growth to the point of limited native grass growth. Eschen et al. (2006) found that carbon addition disproportionately reduced aboveground biomass accumulation of a) annual vs. perennial plants and b) grasses compared to forbs and legumes. They posited that this could facilitate species-rich restorations, as annual plants and grasses often dominate early succession on ex-arable land. Similarly, our result showed that carbon addition may not be a useful restoration tool for grass species.

In a glasshouse experiment testing modes of carbon application (surface applied or incorporated into soil), Bleier and Jackson (2007) noted that surface applied sugar and sawdust resulted in a dense layer of substrate on the soil surface throughout the season. They suggested that this acted as a slow-release mechanism providing carbon to microbes throughout the season, but found that it did not affect C4:C3 grass ratio. In our experiment, the sawdust was applied on top of the existing vegetation, but quickly sifted through the foliage and landed on the soil surface. We did not notice a firm "cap" of sawdust develop over time. Sawdust was apparent in some areas of the +C plots throughout the growing season, and this could have impeded the emergence and growth of native grass seedlings to some extent in the years it was applied. However, sawdust was not applied in 2006 or 2007, and therefore would not have caused continuous physical suppression of native plants over the study period.

Nitrogen effect

Nitrogen addition is known to reduce species richness in grasslands (Wedin and Tilman, 1996; Silvertown et al., 2006) and nutrient levels may need to be lowered for a successful restoration (Pykala, 2005). Nitrogen addition can lead to increased aboveground production resulting in competitive exclusion, as shown by Foster and Gross (1998). They found that nitrogen addition increased productivity of the existing grassland thereby reducing recruitment of big bluestem (introduced as seed) by inhibiting its germination and survival. Our data showed greater or equal aboveground productivity under nitrogen addition compared to ambient and carbon plots. Those times of greater productivity may have limited native grass recruitment. In addition, mechanisms other than enhanced pasture productivity could have contributed to the failed recruitment of native grasses under nitrogen addition. Vinton and Goergen (2006) found that under nitrogen addition, smooth bromegrass (C3) altered its morphology and development to give it a competitive advantage—i.e., increased tiller density, mass, and canopy interception—while switchgrass (C4) did not. Nitrogen addition could have caused similar changes that were not detected by our measurements.

Implications for management

Carbon addition is a temporary situation best viewed as a window of opportunity rather than a long-term treatment (Prober et al., 2005)—it requires time, labor, and financial inputs, and could rapidly become infeasible for large areas of land. Our results suggest that it may not be as effective as commonly thought, and that it can actually hinder native grass recruitment in the short-term. Likewise, additions of nitrogen can inhibit native grass recruitment and should be suspended during native grass establishment. Greater establishment of native grasses may occur under spring burning of pastures. This would require the farmer to remove some land from production in the fall to accumulate fuel-load and in early spring when grazing would be deferred while native grasses established. Farmers may be willing to trade this forage production for a successful establishment of native grasses, especially since it would allow them to avoid complete pasture renovation. After the establishment phase, other coexistence mechanisms, such as climate variability (Adler et al., 2006), differences in phenology (Fargione and Tilman, 2005), and soil water partitioning (Nippert and Knapp, 2007) may help maintain a C3-C4 grass coexistence, but future research is needed to determine how management can help to facilitate this.

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TABLES

TABLE 1. Variables used in regression trees as potential predictors of 2006 and 2007 native grass tiller density

Variable	Time points
Soil gravimetric water content (w/w)	June 2004, Nov 2004, May 2005, July 2005, October 2005, May 2006, July 2006
Net nitrogen mineralization (ug N gds^{-1} d^{-1})	June 2004, Nov 2004, May 2005, July 2005, October 2005, May 2006, July 2006, Oct 2006
NH_4^+ pools (ppm)	June 2004, Nov 2004, May 2005, July 2005, October 2005, May 2006, July 2006, Oct 2006
NO_3^- pools (ppm)	June 2004, Nov 2004, May 2005, July 2005, October 2005, May 2006, July 2006, Oct 2006
Soil silt (%)	Oct 2005
Soil sand (%)	Oct 2005
Soil clay (%)	Oct 2005
Aboveground net primary production (g m^{-2} y^{-1})	2004, 2005, 2006
Belowground net primary production (g m^{-2} y^{-1})	2005, 2006
Soil carbon:nitrogen	June 2004, Nov 2004, May 2005, July 2005, October 2005, May 2006, July 2006
Soil nitrogen (%)	June 2004, Nov 2004, May 2005, July 2005, October 2005, May 2006, July 2006
Soil carbon (%)	June 2004, Nov 2004, May 2005, July 2005, October 2005, May 2006, July 2006
Species cover[1] (%)	June 2004, Sept 2004, May 2005, Sept 2005; May 2006, Sept 2006
Bare ground cover (%)	June 2004, Sept 2004

[1]Species with > 10% average cover (n=38)

TABLE 2. ANCOVA output from the mixed-effects model with native grass density (tiller m^{-2}, transformed as $\log[\sqrt{y}+1]$) regressed on treatment combinations (disturbance, soil amendment, seeding time) with year as a continuous covariate.

Parameter	Interpretation	Value	df	t-value	P-value
Intercept	Grand intercept	0.399	50	1.985	0.052
Year	Grand slope	0.419	50	5.342	<.0001
Disturbance	Intercept adjustment for grazed plots	0.169	2	0.841	0.489
Seeding time	Intercept adjustment for spring seeded plots	0.367	5	2.73	0.041
Soil amendment	Intercept adjustment for ambient plots	-0.232	50	-1.343	0.185
Year × disturbance	Slope adjustment for grazed plots	-0.508[1]	50	-6.991	<.0001
Year × soil amendment	Slope adjustment for ambient plots	0.180[1]	50	2.346	0.023

[1]This value indicates the direction and magnitude of difference from the grand slope.

FIGURES

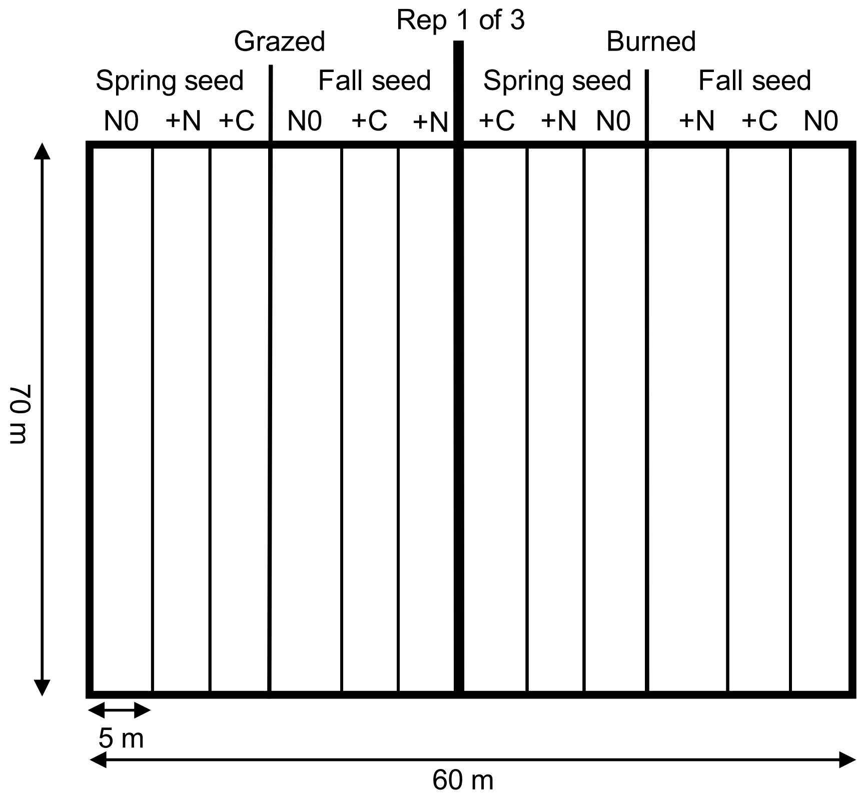

FIGURE 1. One of three blocks of the split-split-split plot field experiment. In the first split, plots were either burned (April 2005 through 2007) or grazed (2004 through 2007) under a monthly rotational grazing system. Under each of those treatments a further split divided plots into seeding time of three native species (see Methods section) in either the fall of 2003 or spring of 2004. Under each seeding time, plots received one of three soil amendments. N0 plots received nothing, +C plots received 1.2 kg sawdust$\cdot m^{-2} \cdot y^{-1}$ (2004 and 2005) and +N plots received 180 kg $NH_4NO_3 \cdot ha^{-1} \cdot y^{-1}$ (2004, 2005, and 2007) applied in split applications (June and August).

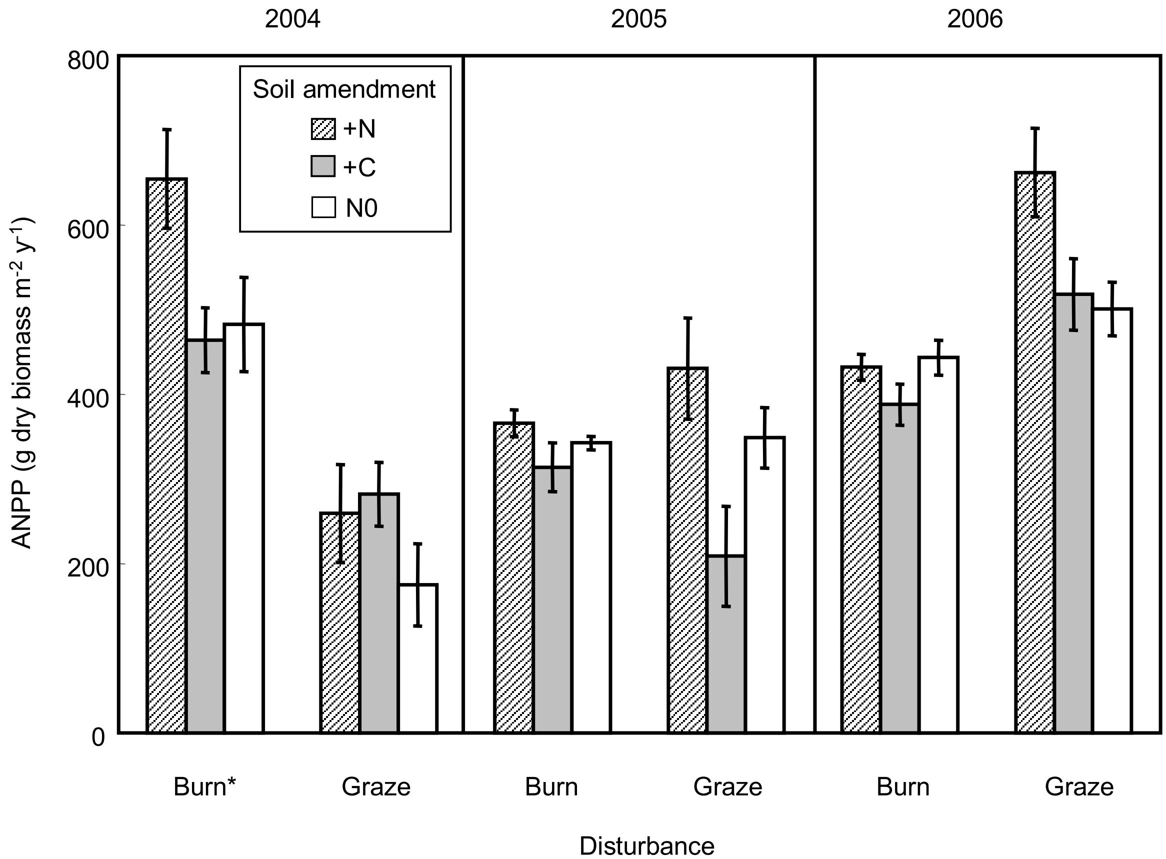

FIGURE 2. Aboveground net primary production (mean, ± one SE, n=6) of plots under disturbance (burn and graze) and soil amendment (nitrogen [+N], carbon [+C] and ambient [N0]) treatments from 2004 through 2006. *The burn treatment was initiated in 2005; in 2004 these plots did not receive a disturbance treatment.

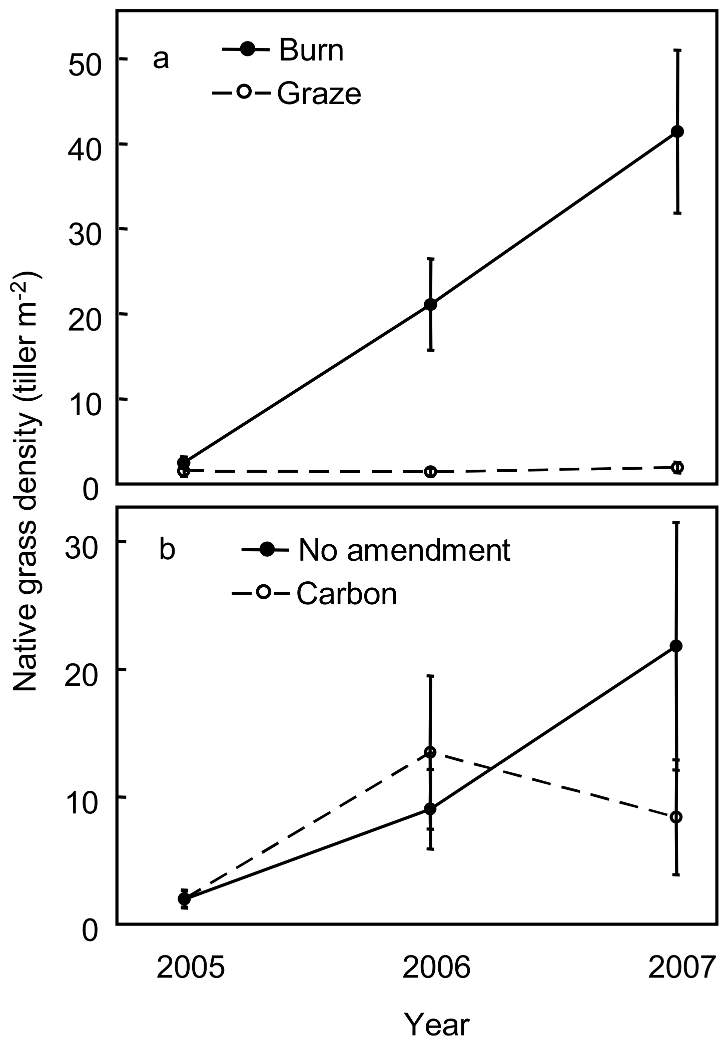

FIGURE 3. Native grass density from 2005 through 2007 (mean, ± one SE, n=12 for 2005 and 2006; for 2007 n=12 for graze, 6 for burn, and 9 for soil amendment plots) under a) disturbance (burn and graze) and b) soil amendment (ambient and carbon) treatments.

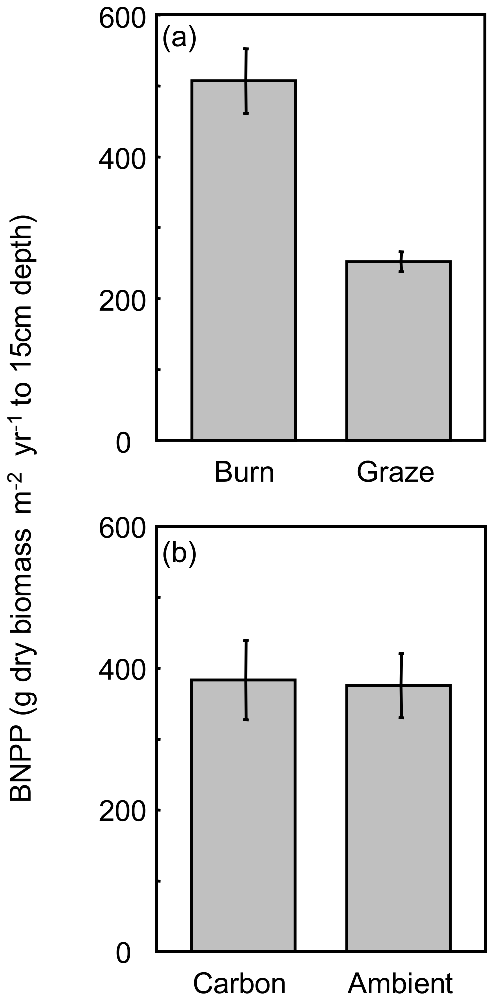

FIGURE 4. Belowground net primary production (mean, ± one SE, n=12) in 2006 for levels of a) disturbance (burn and graze) and b) soil amendment (carbon and ambient) treatments.

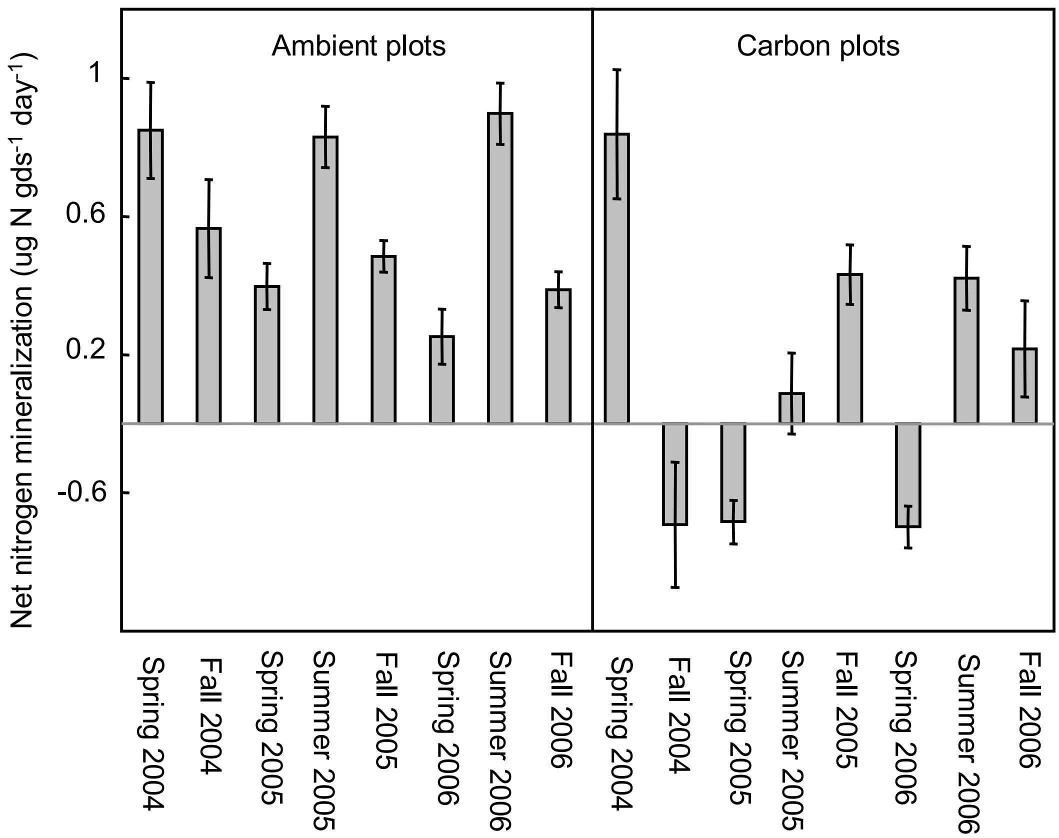

FIGURE 5. Net nitrogen mineralization (mean, ± one SE, n=12 [n=11 for spring 2005 ambient; n=24 for fall 2005, spring 2006, and summer 2006]) from 2004 through 2006 for ambient and carbon amendment plots.

Chapter 3. Separating environment and management effects on a subhumid pasture community

ABSTRACT

Many annual cropping lands are being converted to perennial pasture in humid and subhumid North America as the economic, social, and environmental benefits of managed grazing become evident. Recent evidence about the positive effects of plant diversity on productivity is driving farmers toward management for more complex species mixes than were promoted historically for grazed pastures, but this emphasis has highlighted a lack of understanding about plant community management in pastures. While these ecosystems are generally classified as equilibrium—implying that the plant community will respond to disturbance in a sensitive, predictable manner—management aimed at manipulating the plant community has proven difficult. To better understand this system we examined sources of variability in the plant community of a subhumid grassland that was subjected to combinations of disturbance (grazing or burning) and soil nutrient amendment (nitrogen, carbon, or ambient) treatments over three years (2004 through 2006). We estimated species cover five times during the study period and ordinated these data with Nonmetric Multidimensional Scaling (NMS). Variance in ordination site scores was ascribed to management (i.e. disturbance or soil nutrient amendment treatment), the environment (i.e. year, season within year, or block), or unexplained (i.e. residual) realms with a linear mixed-effects model. The overwhelming source of variability in the plant community was management. Ordination results indicated that plant functional groups sorted out along management gradients: burned plots were shifted towards grasses while forbs were associated with grazed plots. Plots that were grazed and had nitrogen applied

clustered towards cool-season (C3) grasses. Our results indicate that disturbance and soil amendments can be used to shape plant communities in subhumid grasslands for specific agronomic and conservation goals. This work demonstrates how a community-level approach can be used to evaluate management regimes in agroecosystems.

INTRODUCTION

In many temperate areas of the United States, species-poor annual cropping systems are being converted to more diverse perennial grasslands for managed grazing (Hanson et al., 1998; Ostrom and Jackson-Smith, 2000; Foltz and Lang, 2005). Historically, farmers were encouraged to plant these pastures to monocultures or binary plant mixes (Sanderson et al., 2004), but recent work suggests that a higher number of species in grasslands may benefit both production and the environment (Hector et al., 1999; Minns et al., 2001; Tilman et al., 2001; Moore et al., 2004; Tracy and Sanderson, 2004). Generally speaking, grassland plant diversity decreases as management inputs increase (Tallowin et al., 2005), but land managers still lack specific information on how to manage species-rich plant communities. Cool-season (C3) pastures with two or more species have been characterized as difficult to sustain (Tracy and Faulkner, 2006), manage, and as inherently unpredictable (Frame and Newbould, 1986; Kessler and Nosberger, 1994). Other work indicates our ability to predict vegetation change under grazing is limited because plant species frequently vary in their response to grazing (Vesk and Westoby, 2001; Pakeman, 2004).

The complexity of grassland communities may not allow high levels of control given our limited ability to scale population-level responses to the plant community—the scale where pasture management is most relevant. In a review by Chapman et al. (2007), the authors stated: “Our ability to manipulate these pasture types to achieve increasingly challenging productivity and environmental targets depends on gaining further understanding of the interactions between grazing behavior and intake, feed supply and demand balance, pasture composition, and grazing method, *against a backdrop of spatial and temporal variability introduced from a range of* *sources*" (emphasis added). To what extent does the backdrop of spatial and temporal variability matter? Do the effects of management outweigh this variability, and if so, by how much? Little evidence exists about the proportional influence of management and the environment on community composition in these relatively resource-rich pasture ecosystems. Understanding the extent to which management affects the plant community will help land managers set realistic management goals and guide future research questions for managed grasslands. The objective of this study was to differentiate the contributions of temporal, spatial, and anthropogenic effects on the variability of a subhumid grassland plant community that was subjected to various management and climatic conditions over three years.

METHODS

Study site

This study occurred on a farm near Spring Green, Wisconsin (43.175 N, -90.067 W) from 2004 through 2006. The climate is temperate-continental with cold winters and warm summers. Average air temperatures range from -7 ^{o}C in January to 20 ^{o}C in July. Temperatures during the study period were close to these averages (Fig. 1). Average annual precipitation is ~850 mm, with about two-thirds of the annual precipitation falling during the growing season, roughly April to October. Yearly precipitation from 2004 through 2006 varied in total amount— 872, 646, and 1141 mm, respectively—and seasonal distribution (Fig 1). The soil of the experiment area was classified as Fayette silt loam. The farm produced beef cattle (*Bos taurus*) using a management-intensive rotational system—this is short duration (<12 hours to three days) grazing with high stocking densities and two to five week rest periods (Paine et al., 1999). The plots in the experiment area all had the same management history—rotational grazing for more than 15 years—and were dominated by non-native C3 grasses but had a relatively high species richness with ~25 species of grasses, forbs, legumes, and sedges (Table 1).

Treatments and data collection

This study was part of a larger framework investigating the establishment of native warm-season (C4) grasses into an existing C3 pasture under a field experiment that tested combinations of management techniques (grazing, burning, and nutrient additions) aimed at manipulating plant-plant and plant-herbivore interactions to promote coexistence of C3 and C4 grasses.

Disturbance and soil amendment treatments were applied from 2004 through 2006 in a hierarchical design (split-split-split) using three 0.5-ha pastures as experimental blocks (Fig. 2). Disturbance treatments (graze or burn) were randomly applied to one-half of each block. Grazing treatments followed the rotational grazing system and were initiated in early June of 2004. The burn treatment occurred in April of 2005 and 2006 and removed 100% of the aboveground vegetation. Burn plots were not defoliated for the remainder of the year. Each disturbance level was randomly split into a fall or spring seeding of native grasses. Fall (November 2003) and spring (May 2004) native grass seeding occurred by drill-seeding three C4 species—*Andropogon gerardii* Vitman (big bluestem), *Panicum virgatum* L. (switchgrass), and *Sorghastrum nutans* (L.) Nash (indiangrass)—at a rate of ~1 g m^{-2} with a seed mix comprised of 70% big bluestem, 15% indiangrass, and 15% switchgrass into an existing 1.5-ha cool-season pasture. Local ecotype native grass seed was collected from a Wisconsin prairie site and used for both fall and spring plantings. A further split of each seeding time treatment level resulted in three subplots randomly assigned to one of three soil amendment levels: ambient (N0), nitrogen fertilization

(+N), or carbon application in the form of sawdust (+C). Carbon addition has been observed to immobilize soil nitrogen making it less available for plant uptake (Wilson and Gerry, 1995; Morghan and Seastedt, 1999; Blumenthal et al., 2003). Because C4 grasses are more nutrient use efficient (Long, 1999), decreased amounts of available nitrogen should give them a competitive advantage relative to the existing C3 grass species. Nitrogen fertilization was included as a treatment as it is a common practice to promote productivity in grazed pastures. The +C plots received sawdust in a split application (June and August) at a rate of 1.2 kg sawdust m^{-2} y^{-1} in 2004 and 2005. The +N plots received 180 kg NH_4NO_3 ha^{-1} y^{-1} applied in a split application (June and August) in 2004 and 2005. The ambient treatment did not receive soil amendments.

Plant species cover was estimated after treatment initiation in September 2004 and twice annually (June and September) in 2005 and 2006 with the line-point method where the first interception of a sharpened rod with any part of herbaceous vegetation was recorded for 10 hits along a 10 × 50 cm quadrat (Heady et al., 1959). This was repeated every 10 m along a 50-m transect for a total of 50 hits per experimental unit. Grasses, legumes, and forbs were identified to the species level except when not possible (i.e. non-flowering carex species). Nomenclature followed Cochrane and Iltis (2000). For interpretation purposes, plant species were grouped into the following functional groups: C3 grass, C4 grass, legume, forb, and other. Table 1 lists the species found and the functional group to which they were assigned. Because the legumes included in the analyses were all clover species, hereafter we refer to the legume functional group as clover.

Data analyses

For each sampling period, total species cover was calculated as total vegetation hits divided by total possible hits for each quadrat. Plant cover data for the five quadrats per experimental unit were then aggregated to get an average plant cover value. This data was compiled into a plot × species matrix. Three rare species, each occurring in less than five percent of the plots, were removed from the matrix (Table 1). We used the Sorensen distance matrix (McCune and Grace, 2002) to calculate a similarity matrix which was subjected to an outlier analysis test. Plots and species with standard deviations greater than 3.0 were deleted as outliers (McCune and Grace, 2002). The matrix was then subjected to Nonmetric Multidimensional Scaling (NMS) (PC-Ord, MjM Software Design, Gleneden Beach, OR) using a random initial configuration of 4 axes. Monte Carlo tests were applied to compare the stress obtained from actual data and randomizations of the data. Those results, interpretation of the scree plot, and the stress levels indicated that a three-axis configuration best described the structure of this data set. The scores from the initial run were used as the starting point for the three-axis configuration, and multiple runs were conducted to avoid the possibility of settling on local minima.

Ordination biplots were visually assessed for patterns in both sample plots and plant functional groups. In contrast to simple pasture mixtures, when managing a diverse pasture it may be more informative to focus on plant functional groups. However, for a more detailed understanding of how the plant community responded to management we looked at correlation coefficients of each species for axes 1 and 2 which are included as part of the ordination output in PC-ORD. These can provide a reasonable descriptor of the relationship between species abundance and position of plots in ordination space. Pearson's r expresses the linear relationship between the ordination scores and an individual species. A high correlation coefficient for axis 1 would indicate that the species' abundance would increase in plots with high axis 1 scores. These coefficients can be very useful for descriptive purposes but misrepresent nonlinear relationships (any unimodal distribution along an ordination axis) (McCune and Grace, 2002).

We partitioned the variance of the plots in the ordination space to show which variables were driving variation in the system. To do this, site scores for each axis were subjected to a linear mixed-effects model (S-plus v.6.0, Insightful Corp., Seattle, WA) using the restricted maximum likelihood (REML) algorithm. All factors were included as random effects, which are variance estimates around the overall mean (intercept), our only fixed effect. The variables disturbance (grazing or burning), seeding time (fall or spring), and nutrient (nitrogen addition, carbon addition, or ambient) we classified as *management* variables, while year (2004, 2005, or 2006), season of sampling (fall or spring), and block (1, 2 or 3) we classified as *environmental* variables. We considered block an environmental variable as it represented different physical locations of the pasture which could affect plant community dynamics. The output table for this model showed the variance components expressed as standard deviations. To partition the variance between variables we divided the standard deviation of a given variable by total standard deviation, calculated as the sum of the standard deviations of each variable and residual standard deviation. This number was then multiplied by 100 to get percent variance explained by that variable.

RESULTS

The best NMS ordination result was a three-axis configuration with a stress level of 18. The r^2 values of the three axes were 0.243, 0.306, and 0.249, respectively, which explained ~80%

of the variation in the data structure. For each axis, the largest source of variability of plot scores stemmed from management (Table 2). Almost all of the variance in axis 1 was related to management, while season of sampling and year contributed to small percentages of the variance for axes 2 and 3, respectively. Because time of seeding accounted for less than 0.10% of variability for each axis, hereafter and in all figures *management* refers to disturbance and nutrient treatments only.

NMS axis 1 plots indicated a separation between the disturbance treatments with grazed plots grouping at the high end and burned plots at the low end (Fig. 3a). Burned +N plots separated further out compared to other treatment combinations (Fig. 3a). Within each disturbance treatment, +N plots were almost always shifted lower compared to N0 and +C treatments. Along axis 2, the burned +N treatment combination separated out from the others with much higher site scores (Fig. 3b). There was no distinct separation between other disturbance-nutrient combinations. A more subtle separation between season of sampling was observed with spring-sampled plots displaying higher scores than fall-sampled plots (Fig. 4b).

Functional group patterns were observed (Fig. 4) with clover and forbs having higher axis 1 scores compared to all C3 and most C4 grasses, indicating a grass to clover-forb gradient. Along axis 2, functional groups separated out with C3 grasses (with the exception of *Festuca arundinacea*) having higher axis scores than C4 grasses. We could not identify clear patterns in either plots or functional groups along axis 3 (data not shown). Table 3 lists Pearson's correlation coefficient for each species on axes 1 and 2. Table 4 summarizes our results and how they relate to management.

DISCUSSION

While the ordination showed separation between plant functional groups, the magnitude of the gradient was limited (the spread of plant species is well within the spread of the plots). That is, in terms of the plots' response to treatments there was an *overlap*, or a shift towards a plant functional group—not a complete type conversion. This would indicate that generally the same species were present across treatments but in different abundances.

Sources of variability

Environmental variables contributed slightly to the variation in the plant community, but management effects dominated. Similar conclusions were reached by others in cool-season pastures (Smith and Rushton, 1994; Clarke, 2003; Norton et al., 2006), indicating that land managers have some ability to alter the plant community based on specific agronomic and/or conservation goals. Studies in Europe that partitioned and assigned plant community variability to management or environmental factors (soil chemistry, topography, slope, etc.) have been equivocal about the extent to which variability stems from management (Myklestad, 2004; Klimek et al., 2007; Lorenzo et al., 2007), although Myklestad (2004) noted that the environmental variables tested (e.g. soil chemistry) can be highly dependent on management. While similar in their objectives, these studies differed from ours in that they were mensurative (sensu Hurlbert, 1984) and classified environmental variables as plot specific physical characteristics (e.g., soil chemistry), while our environmental variables were temporal or spatial (e.g., season).

Under rotational grazing, dominant plant species have differed among months of a grazing season but remained similar between years (Martz et al., 1999; Karsten and Carlassare, 2002), suggesting less vulnerability to yearly external variables, at least for the dominant species. In contrast, Knapp et al. (2002) found species composition in western tallgrass prairie responded to precipitation variability even with total annual precipitation held constant. Tallgrass prairies are commonly dominated by C4 grasses, which decrease in abundance such that species richness or diversity increases when subjected to disturbances such as grazing or burning. Cool-season grassland agroecosystems lack these C4 grasses. Even in our experiment where C4 grasses were directly seeded into the pasture, after three years *Andropogon gerardii* and *Sorghastrum nutans* contributed to only a small fraction of species abundance (data not shown) and *Panicum virgatum* was never detected with the line-point sampling method. While a significant body of literature has addressed the effects of management and environmental variables on species composition of the tallgrass prairie (Collins, 1987; Gibson et al., 1993; Collins et al., 1998; Baer et al., 2004), how these effects influence cool-season pastures or mixed cool- and warm-season grass pastures is largely untested.

Relevance to management

Shifts in plant species could affect forage quality and quantity, animal intake and performance, and the amount of carbon sequestered. The plant functional group gradients we detected along NMS axes 1 and 2 may be of particular interest to land managers. Axis 1 represented a gradient from grasses on one end to forbs, including nitrogen-fixing clovers, on the other. Virtually all of the variability in this axis was attributable to management. Plots that were grazed had higher axis 1 scores and were thus situated closer to the clover/forb end of the gradient. Cattle preferentially select clover species and their higher tissue quality over grasses (Chapman et al., 2007), but the resulting effects at the community level are equivocal—some studies noted reduced clover cover under rotational grazing (Culvenor, 2000; Chapman et al., 2003) while others reported an increase (Harmoney et al., 2001; Pavlu et al., 2006). Intensive grazing can be beneficial to species preferring high light levels (Pakeman, 2004; Pykala, 2005). In particular, short statured species can benefit from grazing as it promotes species that are lost when tall plant canopies dominate (Fensham et al., 1999; Bullock et al., 2001). This could explain why the short statured C3 grass, *Poa pratensis,* had a larger correlation coefficient with Axis 1 than taller C3 grass species (Table 3).

Research conducted in the tallgrass prairie indicates that frequent spring burning favors dominance of C4 grasses by damaging C3 grasses and forbs (Howe, 2000), removing the detritus layer (Knapp and Medina, 1999), and reducing nitrogen availability (Turner et al., 1997; Brye et al., 2003). The C4 grasses that were seeded into the existing pasture were situated closest to the burned +C and burned N0 treatments in ordination space indicating that, at least during establishment years, these native prairie species responded better to burning with no nitrogen application than any grazing × soil amendment combination. Similar to our results, in grasslands in southern Germany, ordination showed that controlled burning resulted in a specific grouping of vegetation compared to grazing, haying, and mulching treatments (Moog et al., 2002). To the best of our knowledge, burning has not been suggested as a management tool for grazed cool-season pastures in the United States, although work in Australia showed that it could be used to manage the species composition of grazed pastures (Orr and Paton, 1997).

Axis 2 represented a gradient from C3 to C4 grasses. Plots under the burned +N treatment were shifted the furthest towards the C3 grasses. From the ordination plots, it appeared that in particular *Elytrigia repens,* a sod-forming C3 perennial grass, was associated with these plots.

This was verified by its extremely high correlation coefficient with axis 2 compared to all other species (Table 3). This grass is a common weed in annual cropping systems of the North Central U.S., and while not a species that is commonly planted in managed pastures, is not one that graziers actively try to eradicate from their fields. It seems that the burned +N treatment gave this C3 grass some competitive advantage over other species. In contrast to other C3 grasses, *Festuca arundinacea* had a very low correlation coefficient with axis 2, which may be explained by its ubiquity as the dominant across all treatments.

Twenty-two percent of the variability in axis 2 was attributed to season of sampling, and plots sampled in the fall were closer to C4 grasses than plots sampled in the spring. This aligns with the phenological differences in C3 and C4 grasses. During the heat of summer, C4 grasses experience rapid growth (Balasko and Nelson, 2003) because of greater resource use efficiency afforded by their photosynthetic pathway (Lambers et al., 1998). In contrast, C3 grasses have low productivity during the hot summer months, which can result in reduced livestock production and performance (Smart et al., 1995; Paine et al., 1999). Integrating C3 and C4 grasses in a production system has been suggested for more uniform forage production throughout the temperate growing season (Jung et al., 1985; Moore et al., 2004).

In addition to being shifted the furthest from C4 grasses, the burned +N plots (and grazed +N plots to a lesser extent) were situated further away from the clovers and forbs along axis 1. Nitrogen fertilization is a common practice to promote forage production in grazed pastures, but at the expense of species richness (Mountford et al., 1993; Wedin and Tilman, 1996) and reduced clover abundance in grazed pastures (Dennis and Woledge, 1985; Simpson et al., 1988; Woledge, 1988; but see Stout et al., 2001). Plant response to carbon addition is equivocal

(Wilson and Gerry, 1995; Morghan and Seastedt, 1999; Blumenthal et al., 2003; Averett et al., 2004; Corbin and D'Antonio, 2004; Gendron and Wilson, 2007) and we found no clear separation of carbon treatments from the others along either axis.

Importance for understanding vegetation dynamics

Much of the current research in cool-season pastures focuses on how many and which species to plant when establishing new pasture. Studies in these agroecosystems have shown that relatively simple communities can be just as productive and stable as more complex communities if they contain both productive and stress-tolerant species (Tracy and Sanderson, 2004; Tracy and Faulkner, 2006). This has lead to the suggestion that the best strategy to increase productivity and improve stability may be to choose two to three well adapted species, especially since maintaining high forage species richness in pastures can be difficult. Nevertheless, the message farmers are receiving from the ecological community is that diverse assemblages may promote productivity (Tilman et al., 1996; Hector et al., 1999), nutrient retention (Tilman et al., 1996), and invasion resistance (Tracy and Sanderson, 2004; Renne et al., 2006), and stabilize production over time (Minns et al., 2001; Moore et al., 2004). Information on plant diversity dynamics at the farm-level is needed for sustainable management and conservation (Vesk and Westoby, 2001; Klimek et al., 2007), but is currently lacking (Sanderson et al., 2004).

CONCLUDING REMARKS

The majority of variability in this subhumid grassland plant community stemmed from the effects of management. We acknowledge that three years is a relatively short period of time, and that long-term research is needed to shed more light on the relative effects of management and the environment on subhumid grasslands. This study showed that these communities can respond rapidly to changes in management. This finding is similar to work in grasslands in Northern England where vegetation shifted quickly in response to management (Smith and Rushton, 1994). Plant functional groups responded to grazing, burning and nutrient additions differently, indicating that these pastures can be manipulated by land managers for specific goals. In addition, we demonstrated a community-level approach that could be used to evaluate management regimes, such as different timings, seasons, and intensities of grazing. Most studies in grazed pasture temperate agroecosystems have focused on the response of particular species or species richness to management. This level of understanding may have been sufficient in the past as farmers were encouraged to manage for simple pasture communities (Nelson and Burns, 2006). However, even management of simple plant mixtures can be difficult, and while greater plant diversity may lead to greater stability of total community biomass, it may simultaneously destabilize abundances of individual species (Rees et al., 2001). As the goals of society and lean towards maintaining and enhancing biodiversity in the landscape (Ehrlich and Wilson, 1991; Duncan, 2005; Tallowin et al., 2005), understanding the extent to which management affects plant community dynamics may offer help to land managers as they balance production and conservation goals.

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TABLES

TABLE 1. List of species found in the field experiment from 2004 through 2006.

Species code	WISFLORA Nomenclature	Common name	Functional group	Pre-treatment[1] cover (%)
Aggi	*Agrostis gigantea* Roth	red top	C3 grass	2.30
Amar	*Ambrosia artemisiifolia* L.	common ragweed	forb	0
Ange	*Andropogon gerardii* Vitman	big bluestem	C4 grass	0
Brin	*Bromus inermis* Leyss.	smooth bromegrass	C3 grass	6.55
Casp	*Carex* sp.	sedge sp.	other	0.94
Cevu	*Cerastium fontanum* Baumg. emend Jalas	mouseear chickweed	forb	0.12
Ciin	*Cichorium intybus* L.	chicory	forb	0
Daca	*Daucus carota* L.	wild carrot	forb	0
Dagl	*Dactylis glomerata* L.	orchardgrass	C3 grass	11.61
Disa	*Digitaria sanguinalis* (L.) Scop.	large crabgrass	C4 grass	0
Elre	*Elytrigia repens* (L.) Desv. ex B.D.Jacks.	quackgrass	C3 grass	2.91
Fear	*Festuca arundinacea* Schreb.	tall fescue	C3 grass	14.79
Fepr	*Festuca pratensis* Huds.	meadow fescue	C3 grass	22.06
Glhe	*Glechoma hederacea* L.	ground Ivy	forb	0.53
Jute*	*Juncus tenuis* Willd.	slender rush	other	0.35
Lase	*Lactuca serriola* L.	prickly lettuce	forb	1.47
Lope	*Lolium perenne* L.	perennial ryegrass	C3 grass	3.16
Mesa*	*Medicago sativa* L.	alfalfa	legume	0
Oxst*	*Oxalis stricta* L.	yellow woodsorrel	forb	0
Phpr	*Phleum pratense* L.	Timothy	C3 grass	6.98
Plsp	*Plantago* sp.	plantain	forb	1.12
Popr	*Poa pratensis* L.	Kentucky bluegrass	C3 grass	15.50
Rucr	*Rumex crispus* L.	curled dock	forb	0.62
Sepu	*Setaria pumila* (Poir.) Roem. & Schult.	yellow foxtail	C4 grass	0.06
Sonu	*Sorghastrum nutans* (L.) Nash	Indiangrass	C4 grass	0
Taof	*Taraxacum officinale* Weber	dandelion	forb	5.24
Trpr	*Trifolium pratense* L.	red clover	legume	1.14
Trre	*Trifolium repens* L.	white clover	legume	0.82

In the ordination plots, the abbreviation 'bare' is bare ground. [1]Pre-treatment data collected in the spring of 2004. *Species occurring in less than five percent of plots during the post-treatment period and not used in ordinations.

TABLE 2. Partitioning of variance of NMS ordination scores for environmental and management variables.

	Percentage of total standard deviation		
Factor	NMS axis 1	NMS axis 2	NMS axis 3
Environmental variables			
Year	<0.001	0.005	14.79
Season	0.001	21.17	<0.001
Block	0.002	0.005	0.007
Management variables			
Disturbance	52.04	14.16	31.61
Seeding time	0.02	0.03	0.007
Nutrient	47.87	47.99	42.49
Unexplained			
Residual	0.07	16.64	11.08

The variables disturbance (grazed or burned), seeding time (fall or spring), and nutrient (nitrogen addition, carbon addition, ambient) we classified as *management* variables, while year (2004, 2005, 2006), season of sampling (fall or spring), and block (1, 2 or 3) we classified as *environmental* variables. Standard deviations are from the output of the linear mixed-effects model with variables as random effects.

TABLE 3. Pearson's Correlation (*r*) for each species for axes 1 and 2 from the NMS ordination. Species codes are translated in Table 1.

Species code	Axis 1	Species code	Axis 2
Fear	-0.481	Fear	-0.822
Elre	-0.384	Sepu	-0.195
Dagl	-0.282	Ciin	-0.15
Ange	-0.143	Disa	-0.142
Lope	-0.142	Ange	-0.127
Amar	-0.101	Sonu	-0.119
Sonu	-0.101	Trpr	-0.116
Aggi	-0.072	Trre	-0.1
Phpr	-0.041	Popr	-0.059
Brin	-0.033	Amar	-0.039
Lase	0.007	Plsp	-0.028
Fepr	0.014	Glhe	-0.019
Casp	0.057	Rucr	0.011
Rucr	0.058	Taof	0.017
Sepu	0.152	Casp	0.021
Cevu	0.157	Fepr	0.029
Bare	0.185	Cevu	0.088
Glhe	0.203	Dagl	0.102
Disa	0.291	Bare	0.154
Trre	0.353	Lase	0.179
Trpr	0.397	Lope	0.195
Plsp	0.412	Aggi	0.208
Ciin	0.442	Phpr	0.229
Taof	0.623	Brin	0.269
Popr	0.639	Elre	0.681

TABLE 4. Summary of NMS axes plant functional group gradients and how they relate to management.

NMS axis	r^2	Functional group gradient	Sources of variability[1]	Management Application
1	0.243	Grass to clover/forb	Disturbance, nutrient	• Grazed plots shifted towards clover/forb; burned plots shifted towards grasses. • Burned+N plots shifted furthest from clover/forb. • Grazed+N plots shifted further from clover/forb compared to other graze plots.
2	0.306	C3 grass to C4 grass	Disturbance, nutrient, & season of sampling	• Burned+N plots furthest from C4 grasses. • Plots sampled in fall closer to C4 gradient.
3	0.249	No clear pattern	Disturbance, nutrient, & year	• No clear pattern.

[1]Sources of variability come from the linear mixed-effects model results where all variables were classified as random variables. We consider a variable to be a source of variability if it contributed to at least 5% of the total variability for a given axis.

FIGURES

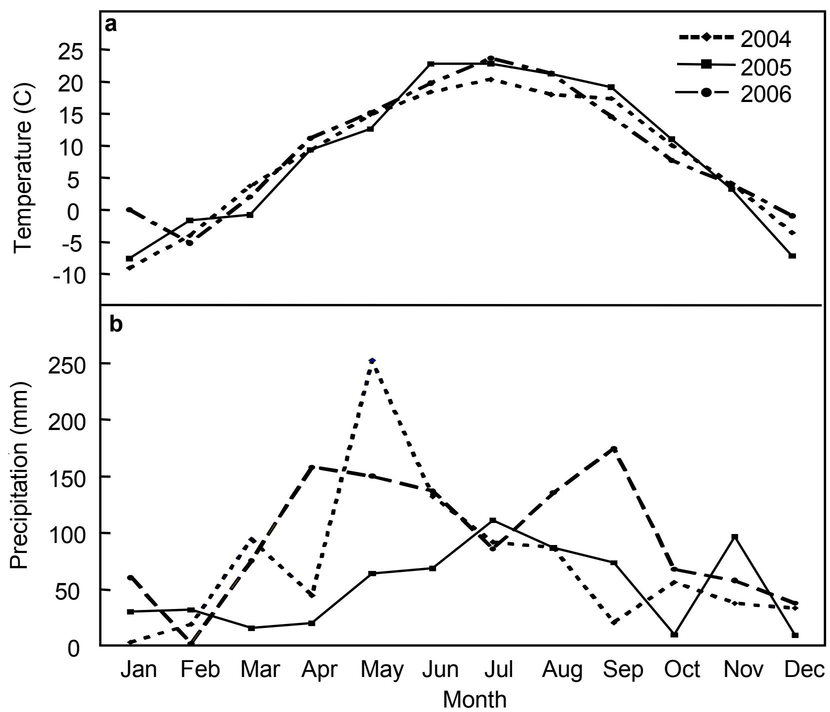

FIGURE 1. Average monthly temperature (a) and total monthly precipitation (b) for Spring Green, WI, from 2004 through 2006.

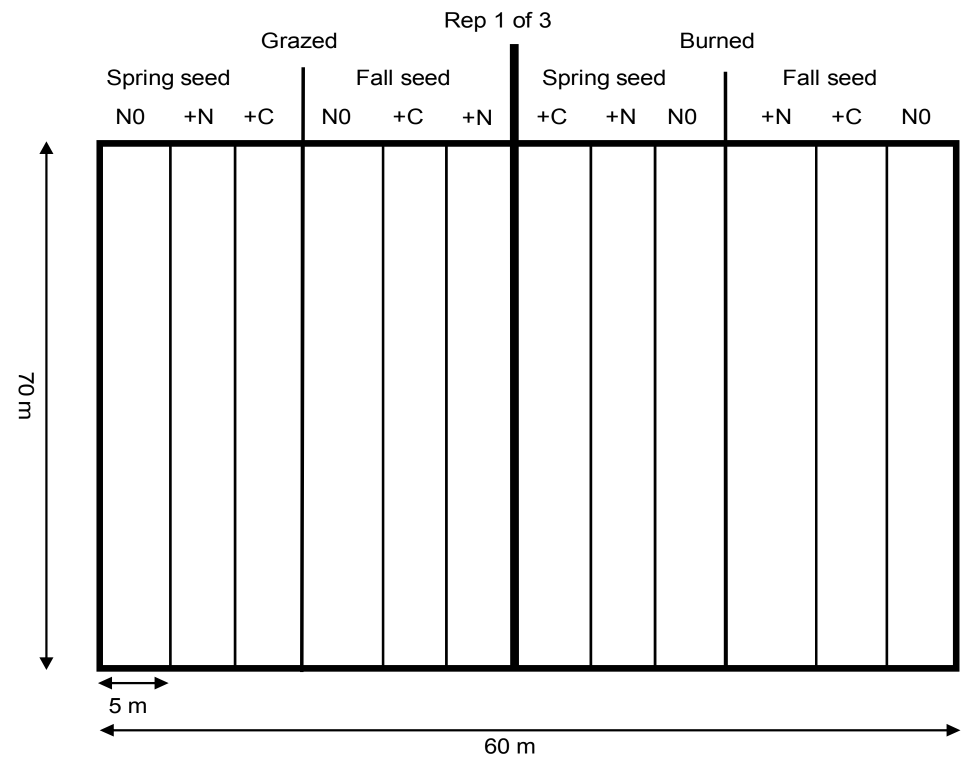

FIGURE 2. One of three blocks of the hierarchical field experiment.

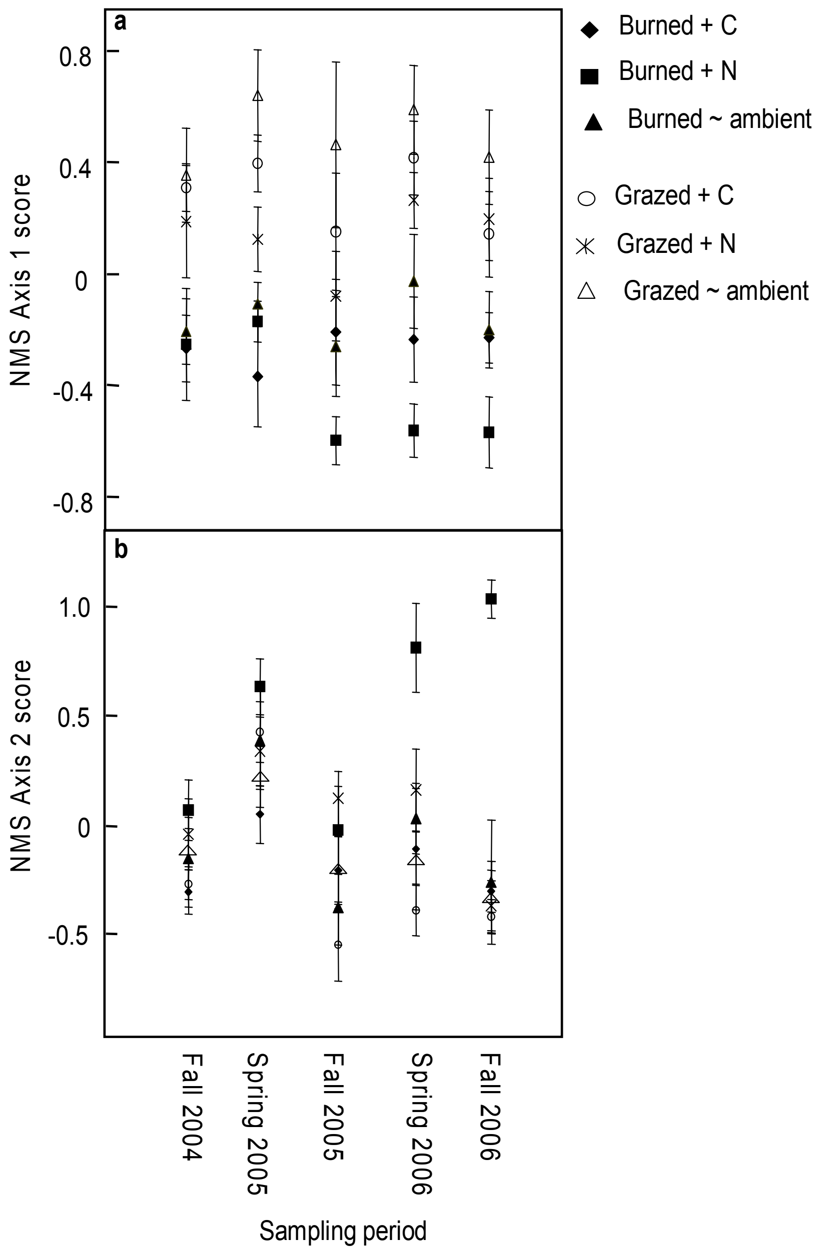

FIGURE 3. Axes 1 (a) and 2 (b) NMS ordination site scores (mean +/- one standard error) plotted for each vegetation sampling time point. (a) Grazed plots (open symbols) had higher scores than burned plots (filled symbols), while plots that received nitrogen were generally shifted lower within each disturbance group. (b) Burned +N plots (filled squares) separated from all other plots.

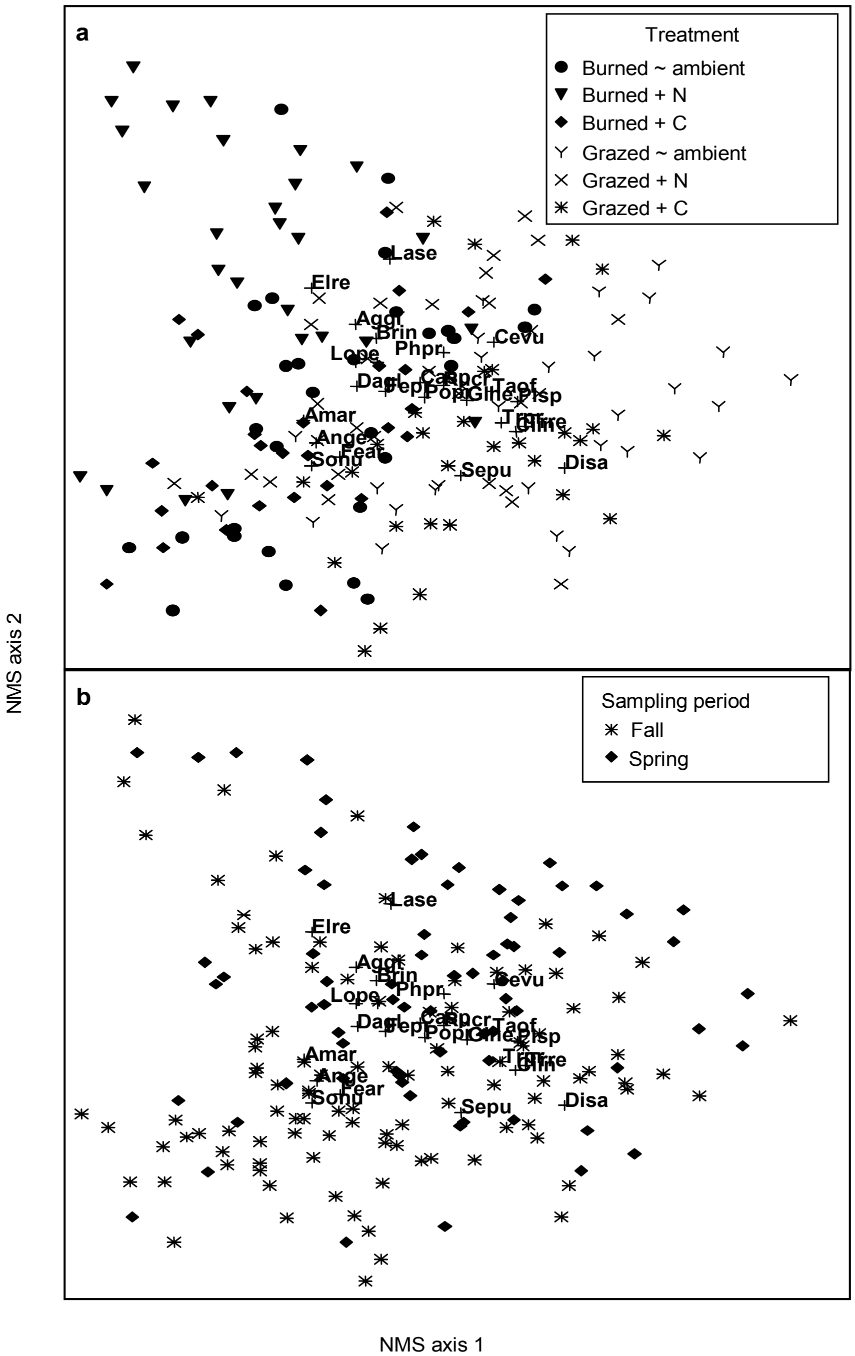

FIGURE 4. Axes 1 and 2 of NMS ordination results from the plot × species matrix. Species are overlaid in ordination space (crosses; see Table 1 for species codes). Plant functional group gradients can be seen with clovers and forbs shifted to the right of axis 1 and grasses shifted to the left. Along axis 2, C3 grasses generally have higher axis scores than C4 grasses. (a) Along axis 1 plots separate by disturbance treatment with grazed plots (lines) shifted to the right and burned plots (solid) shifted to the left. Within each disturbance treatment, plots that received nitrogen are slightly shifted to the left. (b) Along axis 2 plots separate by season of sampling with fall sampled (stars) generally shifted lower than spring sampled (diamond) plots.

Chapter 4. Effects of prairie restoration management on above- and belowground pasture production and forage quality

ABSTRACT

Multifunctional agricultural landscapes and the ecosystem services they provide are gaining more attention. One example is the reintroduction of native species to cool-season grassland agroecosystems managed for livestock production. While such projects have potential ecological and agronomic benefits, there is little information on how restoration type management affects pasture production and quality. The objective of this study was to determine how management to establish native warm-season grasses into temperate pastures affects forage production and quality. We tested this over three years (2004 through 2006) using a field experiment with combinations of disturbance (burning and grazing), soil amendments (ambient, nitrogen, and carbon), and native grass seeding times (fall and spring). We measured aboveground net primary production (ANPP), belowground net primary production (BNPP), and two forage quality parameters—neutral detergent fiber and in vitro neutral detergent fiber digestibility. For ANPP, there was a significant disturbance × soil amendment interaction effect in each year, but the nature of the interaction varied by year. In 2005, plots where nitrogen was applied had lower BNPP than carbon and ambient plots. In 2006, burned plots had greater BNPP than grazed plots. For each level of disturbance, over 50% of the variability in the forage quality parameters was attributed to non-management variables, such as season. Our results showed no consistent effect of restoration management on pasture production or quality. They highlight the complexity of grassland agroecosystems and demonstrate the importance of evaluating the variability of treatment effects over time.

INTRODUCTION

The loss of tallgrass prairie in the central United States has had profound ecological consequences (Rhemtulla et al., 2007). This has fueled a burgeoning prairie restoration enterprise and motivated research into how to best facilitate re-introduction of native species (Brye et al., 2002; Averett et al., 2004). Most of these restoration efforts have been in non-agricultural or recently abandoned agricultural areas. There have, however, recently been attempts to directly seed native prairie species into agricultural pastures comprised of exotic cool-season species (Jackson, 1999; Waldron et al., 2005; Douglas et al., 2007). Such efforts address the growing interest in multifunctional production systems where both agricultural commodities and ecological services are produced from landscapes (Jordan et al., 2007). The number of policy initiatives to encourage management that supports diversity/conservation objectives in temperate grasslands has grown in recent years and the trend towards multifunctionality is likely to increase (Hopkins and Wilkins, 2006). While multifunctional landscapes may provide new income opportunities to grass-based farmers, they also present technical challenges (Hopkins and Wilkins, 2006). Incorporating native warm-season grasses into cool-season pastures is a relatively new approach, so there is a paucity of information about how prairie restoration and management associated with establishing prairie species may affect the forage production and quality of existing pastures. If there are large tradeoffs in production, farmers may be less willing to integrate native species into their farming systems.

A common goal for both natural and managed grasslands is to maintain or promote plant diversity and productivity, and often management for production and restoration are complementary towards this end (Guo, 2007). However, the goals of production and restoration/conservation may not always be compatible. While recognizing the desire of many to find management strategies that simultaneously address ecological and agronomic goals, Dorrough et al. (2004) suggested that in many cases this may not be possible. They posited that such projects are likely to be more successful in low-input, low-productivity sites. Likewise, White et al. (2004) concluded from a mensurative study comparing forage production from pastures with a range of plant diversity that “there appear[s] to be few reasons to encourage diverse plant communities in production-oriented forage systems.” Increased plant diversity in semi-natural (low-input, highly diverse) grasslands has resulted in reduced forage quality and production relative to more intensively managed, low-diversity pastures (Tallowin and Jefferson, 1999; Bruinenberg et al., 2002). Conversely, many studies have found that a higher number of species in grasslands may benefit both production and the environment (Tilman et al., 1996; Hector et al., 1999; Minns et al., 2001; Tilman et al., 2001). However, while informative, these studies focused on diversity per se and lack information on how the *management* aimed at increasing diversity might affect production.

We assessed forage production and quality of pastures subjected to native grass restoration management. Treatments included drill-seeding native species (spring and fall), disturbances (grazing and burning) and soil amendments (carbon, nitrogen, and ambient).

METHODS

This study was conducted on a farm in southwestern Wisconsin (43.175 N, -90.067 W). The climate is temperate-continental with cold winters and warm summers. Average temperatures range from -7 ^{o}C in January to 20 ^{o}C in July. Temperatures during the study period (2004 through 2006) were close to these averages. Average annual precipitation is ~850 mm, with about two-thirds of the annual precipitation falling during the growing season, roughly

April to October. Yearly total precipitation amounts for 2004 through 2006 were 872, 646, and 1141 mm, respectively. The soil of the experiment area was classified as Fayette silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). The farm produced beef cattle (*Bos taurus*) using a management-intensive rotational system, which is short duration (<12 hours to three days) grazing with high stocking densities and two to five week rest periods (Paine et al., 1999). The experiment area had been under this type of grazing for more than 15 years and was dominated by non-native C3 grasses, but had a relatively high species richness with ~25 species of grasses, forbs, legumes, and sedges.

Treatments and data collection

Disturbance and soil amendment treatments were applied from 2004 through 2006 in a hierarchical design (split-split-split) using three 0.5-ha pastures as experimental blocks (Fig. 1). Disturbance treatments (graze or burn) were randomly applied to one-half of each block. Grazing treatments followed the rotational grazing system and were initiated in early June of 2004. The burn treatment occurred in April of 2005 and 2006, and plots that were burned were not defoliated for the remainder of the year. Plots under different disturbance levels were separated by electric fences. Each disturbance level was randomly split into a fall or spring seeding of native grasses. Fall (November 2003) and spring (May 2004) native grass seeding occurred by drill-seeding three native warm-season grasses—*Andropogon gerardii* Vitman (big bluestem), *Panicum virgatum* L. (switchgrass), and *Sorghastrum nutans* (L.) Nash (indiangrass)—at a rate of ~1 g m^{-2} with a seed mix comprised of 70% big bluestem, 15% indiangrass, and 15% switchgrass into an existing 1.5-ha cool-season pasture. Local ecotype native grass seed was collected from a Wisconsin prairie site and used for both fall and spring plantings. A further split of each seeding time treatment level resulted in three subplots randomly assigned to one of three soil amendment levels: ambient (N0), nitrogen fertilization (+N), or carbon addition (+C). The +C plots received sawdust in a split application (June and August) at a rate of 1.2 kg sawdust m^{-2} y^{-1} in 2004 and 2005. The +N plots received 180 kg NH_4NO_3 ha^{-1} y^{-1} applied in a split application (June and August) in 2004 and 2005. The ambient treatment did not receive soil amendments.

In 2004, aboveground net primary production (ANPP) was estimated by monthly clipping biomass from two 10 × 50 cm quadrats randomly placed in each experimental unit. In 2005 and 2006 we calculated ANPP from an allometric relationship with leaf area index (LAI, r^2=0.84), which was calculated from intercepted photosynthetically active radiation (PAR) readings (Accupar LP-80, Decagon, Inc., Pullman, WA) made above and below the leaf canopy at four points along each experimental unit. For each experimental unit, biomass weights (2004) and LAI readings (2005 and 2006) were averaged to estimate biomass per experimental unit. Clippings and LAI readings were taken monthly for plots that were burned and before and after each grazing event for grazed plots and summed to calculate ANPP. Belowground net primary production (BNPP) was estimated with root ingrowth cores (Bledsoe et al. 1999) where two soil cores per experimental unit were removed prior to the growing season and sieved. The cores were 5 cm in diameter and taken to a depth of 15 cm. The soil was returned to cores of the same dimensions fashioned of 2-mm plastic mesh material, inserted back into the original hole, and harvested at year's end. The root biomass was washed, dried to constant weight at 60° C, and weighed. For each experimental unit, the two root weight values were averaged for an estimate of BNPP.

In the spring, summer, and fall of 2004 through 2006 we estimated two forage quality parameters—neutral detergent fiber (NDF, calculated as percent of dry matter) and in vitro neutral detergent fiber digestibility (IVNDFD, calculated as percent of NDF). Neutral detergent fiber is a measure of the total cell wall constituents including hemicellulose, and it is used to predict forage intake potential. A rise in NDF indicates a decline in forage quality and voluntary feed intake (Ball et al., 2001). In vitro digestibility analyses are considered the best way to predict animal performance (Ball et al., 2001). In vitro neutral detergent fiber digestibility is a good forage quality parameter to compare forages, and it is best used to track changes in forages on the same operation from different defoliation events and years (Soychlor, July 2006). Forage samples were clipped from one 10 × 50 cm quadrat in each experimental unit (in 2006 two quadrats per experimental unit). Burned and grazed plots were clipped on the same day except in two instances—fall 2004 and spring 2005. Clipping dates were: June 3, July 14, and September 3/5 in 2004; April 22/27, July 11, and September 16 in 2005; May 18, July 5, and September 7 in 2006. Biomass was dried at 60^0 C to constant weight and ground through a Wiley mill (info) equipped with a 1-mm screen. Samples were analyzed for forage quality by calibrated near infrared reflectance spectroscopy (NIRS). Calibration samples (n=56) were chosen based on spectra files of all samples using WinISI II Version 1.50 software (Infrasoft International, LLC, Prt Matilda, PA) and analyzed in the laboratory for IVNDFD (Goering and Van Soest, 1970) and NDF (Mertens et al., 2002).

Statistical analyses

We performed separate ANOVAs for ANPP and BNPP for each year, three for ANPP (2004 through 2006) and two for BNPP (2005 and 2006). Significance was determined at the $\alpha=0.05$ level. When there were significant interactions, Tukey's multiple comparison tests were applied to separate means with an experiment-wise error rate of $\alpha=0.05$.

Plots of means and standard errors were visually assessed for patterns in forage quality parameters. Based on these assessments, and the results from ANPP and BNPP ANOVAs showing interannual variation in response to treatments, we were interested in comparing the relative magnitude of variability in forage quality from management and non-management variables. Because it is well established that forage quality decreases with plant maturity (Bruinenberg et al., 2002; Hopkins and Wilkins, 2006), we were not interested in comparing differences between burned and grazed plots. Plants that were burned in early spring were left to grow the remainder of the season with no defoliation, and we would expect forage quality to be lower in these plots. Therefore, the data was split by disturbance treatment into two sets. For each set, we partitioned the variance of NDF and IVNDFD to show how factors contributed to the variation in these forage quality parameters. To do this, NDF and IVNDF values for each experimental unit were subjected to a linear mixed-effects model (S-plus v.6.0, Insightful Corp., Seattle, WA) using the restricted maximum likelihood (REML) algorithm. All factors were included as random effects, which are variance estimates around the overall mean (intercept), our only fixed effect. The variables seeding time (fall, spring) and nutrient (nitrogen addition, carbon addition, ambient) we classified as *management* variables, while year (2004, 2005, 2006), season of sampling (spring, summer, fall), block (1, 2, 3), and residual variance we classified as *non-management* variables. The output table for this model showed the variance components expressed as standard deviations. To partition the variance between variables we divided the standard deviation of a given variable by total standard deviation, calculated as the sum of the standard deviations of each variable and residual standard deviation. We then multiplied this number by 100 resulting in a standardized coefficient of variation for each factor (Jackson et al., 2007).

RESULTS AND DISCUSSION

Aboveground net primary production

There was a significant disturbance × soil amendment interaction for each year (Table 1). However, the nature of that interaction varied by year (Fig. 2). It is well established that grassland ANPP response to management is sensitive to the nature and timing of treatments and environmental factors. In prairies and cool-season pastures, productivity and grass tiller density have been found to decrease under no disturbance due to the accumulation of detritus (Knapp and Seastedt, 1986; Nie et al., 1997). In general, prairie production is higher on burned sites compared to unburned sites. This is attributed to the increased productivity and dominance of warm-season grasses under burning (Collins and Steinauer, 1998). However, when grown in monocultures, burning in combination with harvesting can reduce productivity of these warm-season grasses (Cuomo et al., 1996). In addition, the timing of burns determines if the productivity of warm-season grasses increases or decreases (Mitchell et al., 1996). Burning is not typically used as a production tool in cool-season pastures, but it is a common management technique used to suppress exotic cool-season grasses and shrubs in restored and remnant prairies. While fire often reduces the abundance of cool-season grasses (Bowles et al., 2003), during certain growth stages and moisture conditions burning can promote the growth of cool-season grasses such as *Poa pratensis* and *Bromus imermis* (Zedler and Loucks, 1969; Willson and Stubbendieck, 1997). Even when management does not alter, grassland production varies by season and year (Kanneganti et al., 1998; Clapham et al., 2008). Our results reflect the complexity of grassland responses to disturbance as reported in the literature.

Belowground net primary production

There were no significant interaction effects on belowground production. In 2005, there was a significant soil amendment effect and in 2006 there was a significant disturbance effect (Table 2, Fig. 3). Multiple comparison tests showed that in 2005 BNPP was lower in plots where nitrogen was applied. In 2006 plots that were burned had greater BNPP than plots that were grazed.

Plant ecology theory predicts that if soil nutrients are readily available, plants will allocate less energy into the growth of roots, but results are equivocal on this matter. Studies report nitrogen addition enhancing (Benning and Seastedt, 1997; Malhi and Gill, 2002), not affecting (Dawson et al., 2003), and limiting root production in the short and long term (Ennick et al., 1980; Rice et al., 1998). When extreme nutrient deficiency exists, root growth may be stimulated by nitrogen application (Klepper, 1991). However, for crop roots and soils that are inherently more fertile, there is less certainty about the effects of fertilizer on BNPP (Schnabel et al., 2001; Malhi and Gill, 2002). The reduction in root growth we measured under nitrogen application could have adverse effects on pasture health and carbon sequestration. However, this pasture ecosystem showed resilience in recovering from the negative effect of nitrogen application: in 2006 (no nitrogen or carbon applied) there was no effect of soil amendment on BNPP.

In 2006, burned plots had greater root production than grazed plots. Burning and rotational grazing remove aboveground biomass in different ways: burning is a discrete event while grazing removes biomass in quasi-monthly pulses. Because of this, these disturbances have differing effects on above- and belowground processes (Johnson and Matchett, 2001). Burning has been found to stimulate root production in tallgrass prairie ecosystems (Rice et al., 1998; Johnson and Matchett, 2001), which has been attributed to warmer soil temperatures in burned compared to unburned sites (Knapp and Seastedt, 1986). Plants can compensate for decreased nitrogen levels under burning by allocating more energy to root growth (Johnson and Matchett, 2001). While herbivory may accelerate rates of carbon and nitrogen cycling leading to increased ANPP (Mawdsley and Bardgett, 1997; Tracy and Frank, 1998), it may suppress BNPP in grasslands relative to ungrazed areas (Guitian and Bardgett, 2000; Johnson and Matchett, 2001; Mousel et al., 2005). However, there is still no general relationship between grazing and changes in root mass (Milchunas and Lauenroth, 1993; Johnson and Matchett, 2001), and in our experiment grazing reduced BNPP in only one of the two years it was measured.

In both years, burning and no soil amendment—treatments that promoted native grass recruitment to the greatest extent (data not shown)—did not negatively affect BNPP. In fact, treatments with lower native grass establishment (grazing, nitrogen addition) had lower root production. Burning was used as a management tool by Native Americans to stimulate grass growth and encourage grazing migrations (Nelson and Burns, 2006). To the best of our knowledge it is not used as a temperate pasture management tool in the United States, although research in Australia indicates that it can be used to manage the species composition of grazed pastures (Orr and Paton, 1997). Temperate grasslands have over 80% of their belowground production in the top 30 cm of soil (Jackson et al., 1996), but native grasses may have twice the deep-root biomass of introduced species (Wilsey and Polley, 2006). This implies that if these native grasses become a significant proportion of the pasture ecosystem, management for them in combination with their deep root production may lead to increased carbon sequestration.

Forage quality

Plots of NDF and IVDNFD showed separation between grazed and burned plots and seasonal variation within each disturbance level (Figs. 4 and 5). Overall, forage from grazed plots had higher quality (greater IVNDFD and lower NDF) than burned plots in the summer and fall. For each disturbance treatment, the largest percentage of variability in forage quality stemmed from non-management factors, for example season, although soil amendment did contribute to variation as well (Table 3).

It is well established that plant maturity has a negative effect on forage quality (Bruinenberg et al., 2002). Even in grazed pastures where biomass is periodically removed and there is younger plant tissue from regrowth, forage quality can fluctuate between seasons (Popp et al., 1997a; Paine et al., 1999; White et al., 2004). Our results support this as 17 to 22% of the variability in forage quality parameters in grazed plots was attributed to seasonality. In fact, in grazed plots over 50% of the variability in forage quality parameters was ascribed to factors outside the control of farmers—in burned plots, it was closer to 70%. Given that treatment effects on ANPP and BNPP differed by year, we were surprised at the low level of interannual variation in forage quality (Table 3). This suggests that certain production parameters are more susceptible to such interannual fluctuations than others.

Soil amendments contributed to variability in forage quality for both disturbance treatments. There were no consistent, clear patterns of the effect of soil amendment in grazed plots (Figs. 4 and 5). In burned plots, nitrogen addition reduced IVNDFD in 2005 and 2006. Newman et al. (2003) found that nitrogen addition lowered IVNDFD of tall fescue. The authors speculated that this could have stemmed from 1) nitrogen leading to a greater proportion of reproductive tillers which have lower forage quality or 2) differences in the proportions of stem and leaf in the grazed horizon between treatments.

Implications for management

We found no consistent effect of treatments for native grass restoration on above- or belowground pasture production. Part of this may stem from the fact that every treatment combination was not applied every year, for example burning did not occur in 2004. However, even when the same treatment was applied in more than one year results varied: there was a disturbance effect on BNPP in 2006 but not 2005, and grazing and burning were applied in both of these years. Our experimental design did not allow us to separate the effects of restoration management from the presence of seeded native grass species. However, the presence of native grasses can be seen as part of a restoration *system*—our results provide farmers with information on how implementation of this system might affect production.

Plots that were burned did have lower forage quality in summer and fall compared to grazed plots, indicating that if farmers wanted to harvest these plots later in the year forage quality would be compromised. There were, however, no consistent, negative treatment effects on pasture production, which has positive implications for the compatibility of restoration and agronomic goals. For certain parameters, restoration management may have positive effects on pasture health, such as greater root production. Although there may be years when restoration techniques adversely affect production, even management aimed at improving pasture production, such as weed control, sometimes redcues forage quantity and quality (Bork et al., 2007). Balancing plant diversity and production in grasslands is difficult for both farmers and ecologists (Guo, 2007), and if the restoration management results in successful establishment of native grasses, farmers may be willing to accept inconsistencies in production for a few years.

Our findings demonstrate that it is difficult to predict how restoration management will affect pasture production and quality, but this is true for production-oriented management as well. Many studies of temperate grazing systems reported significant year × treatment effects on pasture parameters, including canopy structure, production, NDF and crude protein (Popp et al., 1997b; Paine et al., 1999; Bryan et al., 2000; Brink et al., 2007). Some of the main conclusions from an extensive study of Wisconsin grazing farms were that 1) forage production and quality were very responsive to fluctuations in weather conditions and these fluctuations interacted with management, resulting in significant differences between years, and 2) while forage quality under rotational vs. continuous grazing was generally higher, it was less predictable (Paine et al., 1999). How to advise farmers to manage their systems in the face of such variability remains a challenge.

From an agronomic perspective, variability in grassland production and quality between years and seasons is undesirable. But, variability is an intrinsic component of healthy, dynamic ecosystems. In many species-poor annual cropping systems, inputs overwhelm the agroecosystem such that outputs, such as corn yields, are generally consistent across vast spatio-temporal scales. In contrast, temperate pastures are dynamic and complex. While farmers can influence forage production by choice of plant material, fertility amendments, and defoliation management, forage quality and yield are also influenced by weather, pests, foliar diseases, species interactions, etc. (Clapham et al., 2008). Indeed, pastures with two or more species have been characterized as difficult to sustain (Tracy and Faulkner, 2006), manage, and inherently unpredictable (Frame and Newbould, 1986; Kessler and Nosberger, 1994). Managing for variability instead of maximum output in these complex agroecosystems should be considered a reasonable goal. In fact, farmers who rely solely on average production values may experience problems as the probability of attaining a yield close to the mean value is relatively low in any given year (Clapham et al., 2008).

This research provides information that will help in the decision-making processes of farmers as they weigh the tradeoffs and benefits of blending ecological and agronomic goals in their farming systems. It may also be used by restorationists who are often interested in manipulating the productivity of exotic, cool-season grasses. More broadly, the results highlight the complexity of grassland agroecosystems and demonstrate the importance of evaluating the variability of treatment effects over time.

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TABLES

TABLE 1. ANOVA results for aboveground net primary production for 2004 through 2006.

	DF	F Value	Pr (f)
2004			
Soil amendment	2	6.269	0.010
Seeding time	1	0.365	0.578
Disturbance	1	6.317	0.128
Disturbance × seeding time	1	0.507	0.516
Disturbance × soil amendment	2	4.261	0.033
Seeding time× soil amendment	2	0.435	0.655
Disturbance × seeding time × soil amendment	2	0.509	0.611
2005			
Soil amendment	2	9.501	0.002
Seeding time	1	0.023	0.886
Disturbance	1	0.163	0.726
Disturbance × seeding time	1	0.657	0.463
Disturbance × soil amendment	2	3.706	0.048
Seeding time × soil amendment	2	0.452	0.644
Disturbance × seeding time × soil amendment	2	2.278	0.135
2006			
Soil amendment	2	5.621	0.014
Seeding time	1	1.552	0.281
Disturbance	1	29.613	0.032
Disturbance × seeding time	1	1.232	0.329
Disturbance × soil amendment	2	4.277	0.033
Seeding time × soil amendment	2	2.763	0.093
Disturbance × seeding time × soil amendment	2	0.887	0.431

TABLE 2. ANOVA results for belowground net primary production for 2005 and 2006.

	DF	F Value	Pr (f)
2005			
Soil amendment	2	9.394	0.002
Seeding	1	7.320	0.054
Disturbance	1	3.420	0.206
Disturbance × seeding	1	0.630	0.472
Disturbance × soil amendment	2	0.132	0.877
Seeding × soil amendment	2	1.784	0.200
Disturbance × seeding × soil amendment	2	1.732	0.208
2006			
Soil amendment	2	0.253	0.780
Seeding	1	1.000	0.374
Disturbance	1	142.526	0.007
Disturbance × seeding	1	0.431	0.547
Disturbance × soil amendment	2	0.214	0.810
Seeding × soil amendment	2	0.015	0.986
Disturbance × seeding × soil amendment	2	2.716	0.096

TABLE 3. Partitioning of variance of forage quality parameters for each level of disturbance (burned or grazed).

	Percentage of total standard deviation			
	NDF		IVNDFD	
Variable	Grazed	Burned	Grazed	Burned
Year	17.56	0.63	10.37	1.60
Season	22.59	61.49	17.44	41.36
Block	0.16	4.08	23.70	18.42
Seeding time	13.87	10.56	0.97	7.77
Soil amendment	32.36	16.94	45.46	23.08
Residual	13.46	6.30	2.06	7.77
Non-management[1]	53.77	72.50	53.57	69.15

[1]Sum of year, season, block, residual percentages. Standard deviations are from the output of the linear mixed-effects model with variables as random effects.

FIGURES

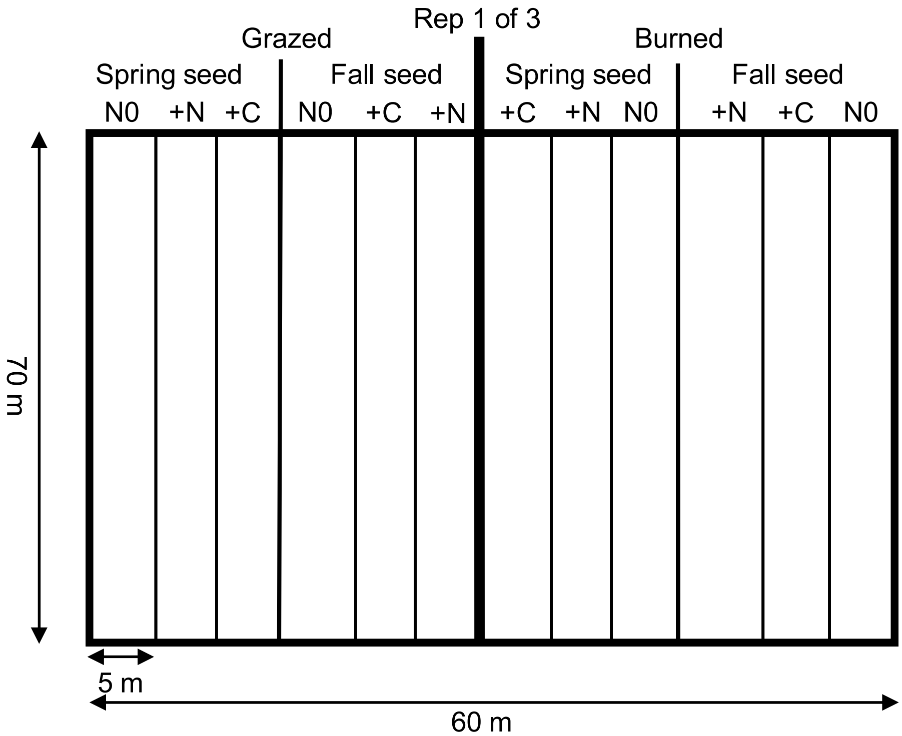

FIGURE 1. One of three blocks of the split-split-split plot field experiment. In the first split, plots were either burned (2005 and 2006) or grazed (2004 through 2006) under a monthly rotational grazing system. Under each of those treatments a further split divided plots into season of seeding of three native species (see Methods section) in either the fall of 2003 or spring of 2004. Under each seeding time, plots received one of three soil amendments. Ambient (N0) plots received nothing, +C plots received 1.2 kg sawdust·m^{-2}·y^{-1} (2004 and 2005) and +N plots received 180 kg NH_4NO_3·ha^{-1}·y^{-1} (2004 and 2005) applied in split applications (June and August).

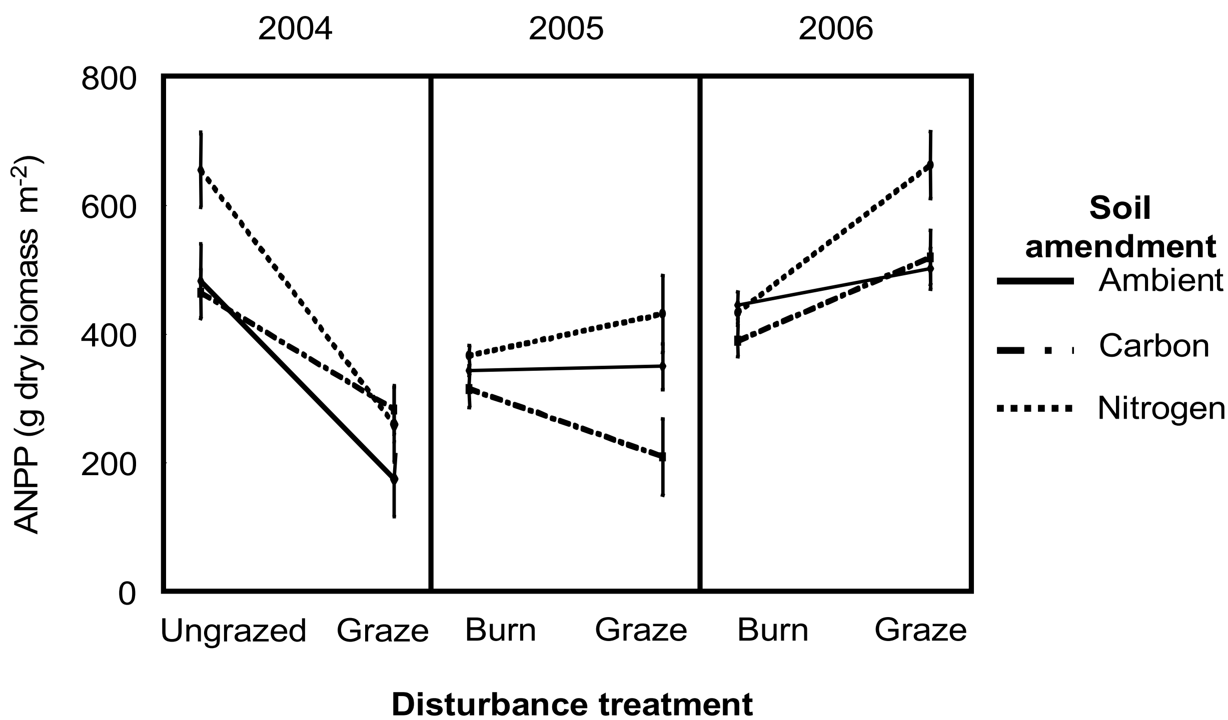

FIGURE 2. Aboveground net primary production (mean, ± one SE, n=6) of plots from 2004 through 2006. ANOVA results showed that each year had a significant disturbance × soil amendment interaction at the α=0.05 level.

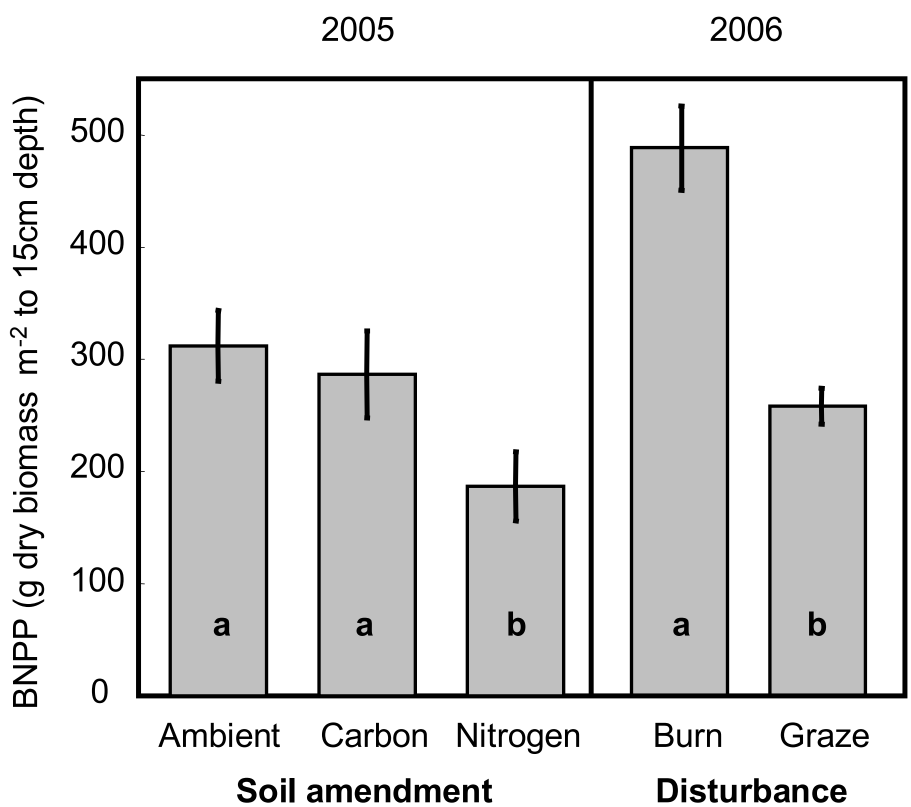

FIGURE 3. Belowground net primary production (mean, ± one SE, n=12 in 2005 and n=18 in 2006) of plots in 2005 and 2006. ANOVA results showed a significant soil amendment effect in 2005 and a significant disturbance effect in 2006. Different letters represent a significant difference (α=0.05) within each year.

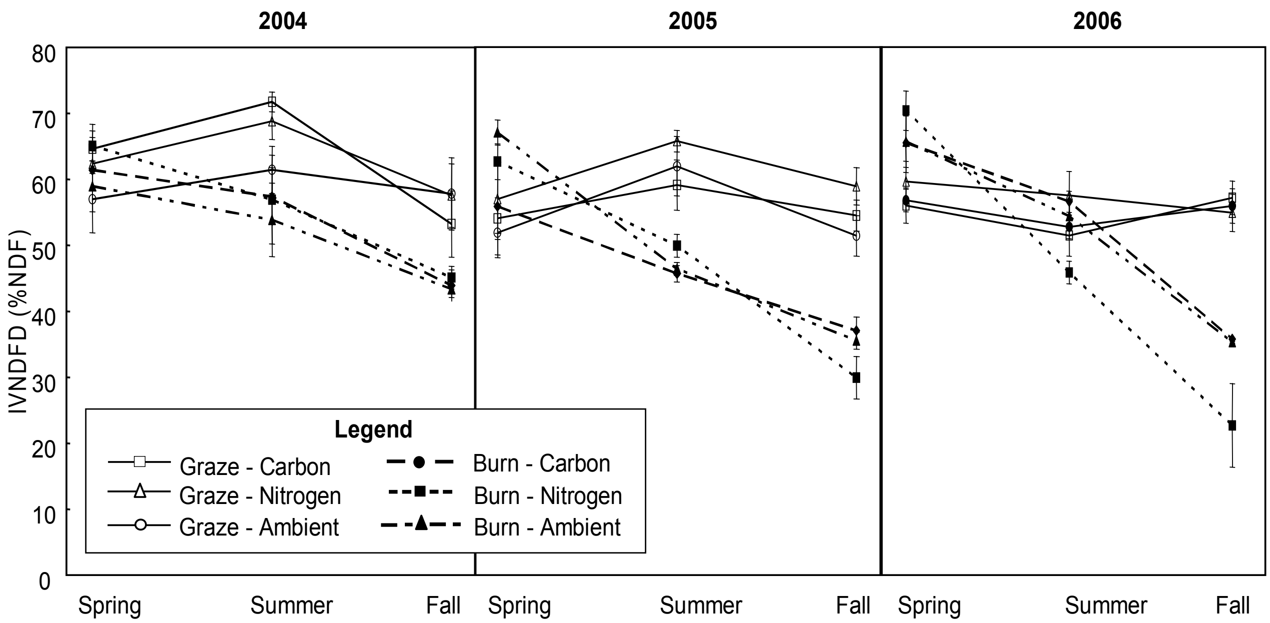

FIGURE 4. In vitro neutral detergent fiber digestibility (%NDF, mean ± one SE, n=6) for plots from 2004 through 2006 for each disturbance and soil amendment treatment combination in the spring, summer, and fall.

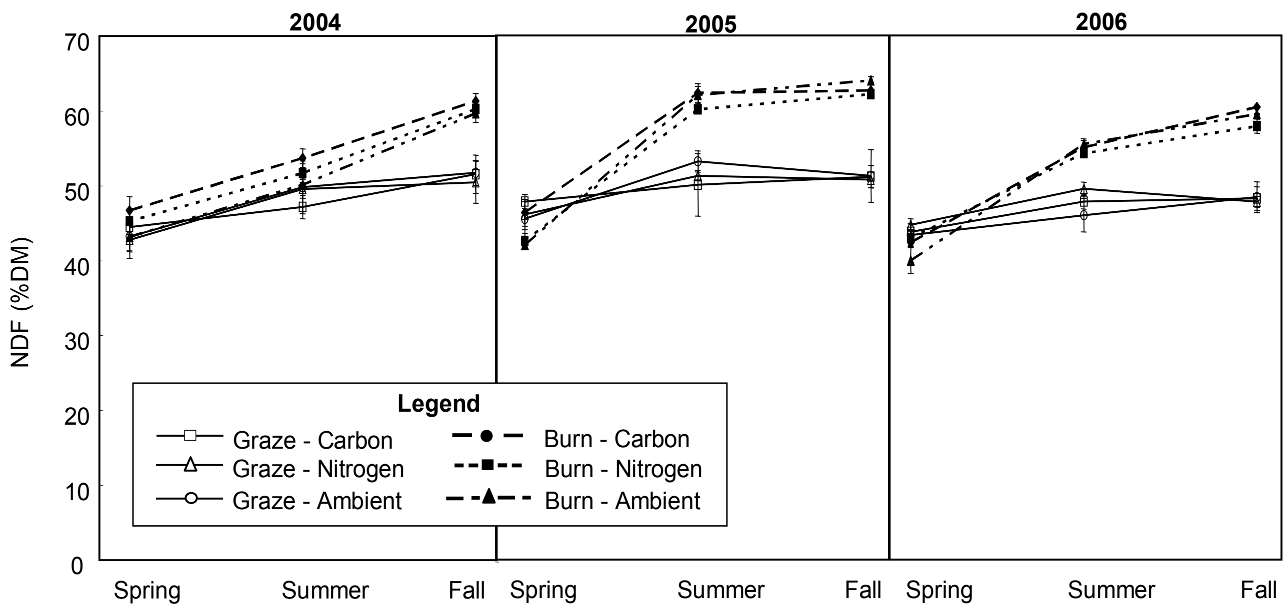

FIGURE 5. Neutral detergent fiber (% dry matter, mean ± one SE, n=6) for plots from 2004 through 2006 for each disturbance and soil amendment treatment combination in the spring, summer, and fall.

Chapter 5. Greenhouse experiments to determine clipping height and frequency effects on the net primary production of *Andropogon gerardii* (C4) and *Bromus inermis* (C3)

ABSTRACT

There are potential agronomic and conservation benefits to incorporating warm-season (C4) grasses into temperate pasture systems, usually dominated by cool-season (C3) grasses, but farmers lack information on how typical management will affect C3 and C4 grasses. We conducted three greenhouse experiments under 1) spring, 2) summer, and 3) spring+summer clipping regimes. In each experiment, we determined clipping frequency and clipping height effects on above- and belowground net primary production (ANPP and BNPP) and total and seasonal forage availability of *Bromus inermis* Leyss (smooth brome, C3) and *Andropogon gerardii* Vitman (big bluestem, C4)—two grasses that are often considered for pasture and prairie seeding. We found different effects of management on two similar metrics: total available forage and ANPP, indicating that our ability to generalize about the effects of management from ecological and agronomic grassland studies is questionable. In all experiments, ANPP and BNPP of smooth brome was higher than big bluestem, although during late summer months big bluestem produced more available forage than smooth brome. Clipping effects on ANPP and BNPP were different for summer clipped pots than for spring and spring+summer pots, suggesting that management could be tailored to meet specific agronomic or conservation goals.

INTRODUCTION

While much of the North Central grasslands fall into what is known as the "tallgrass prairie peninsula", where native warm-season (C4) grasses like big bluestem (*Andropogon gerardii),* switchgrass (*Panicum virgatum*), and indiangrass (*Sorghastrum nutans*) dominated, most of these grasslands are now comprised of cool-season (C3) forages introduced by agronomists and farmers in the late 19th Century (Curtis, 1959). These temperate cool-season grasslands are quite similar with respect to floristic composition, physiognomy, and phenology throughout the Upper Midwest and the Northeastern USA (Sanderson et al., 2004; Tracy and Sanderson, 2004). These pastures are typically sown to C3 perennial grasses and legumes and fertilized to improve forage production (Barnes et al., 1995; Riesterer et al., 2000). C3 forage production is usually greater than livestock consumption early in the growing season, but "slumps" under warmer temperatures of late summer leading to reduced livestock production and performance (Casler et al., 1998; Riesterer et al., 2000; Balasko and Nelson, 2003).

The photosynthetic pathway of C4 grasses affords them higher water use efficiency and therefore less water stress during drier periods (Lambers et al., 1998), resulting in greater production in hot, dry conditions compared to C3 grasses. Combining the abilities of various plant functional groups to maintain both forage quantity and quality throughout the growing season has been suggested by rotating cattle from C4 to C3 pastures (Smart et al., 1995; Moore et al., 2004), establishing C4 grasses with legumes (Posler et al., 1993; Springer et al., 2001), and combining C4 and C3 grasses in a pasture (Bryan et al., 1984; Jung et al., 1985; Jackson, 1999). These studies indicate equivocal results on forage yield for C4 grass–legume systems compared to C4 grasses alone (Posler et al., 1993; Springer et al., 2001) and rotation of cattle from C3 to C4 pastures resulted in equal or less cattle weight gain (Smart et al., 1995; Moore et al., 2004).

Producers interested in combining C3 and C4 grasses in their grazing system should benefit from information about whether combining these functional groups benefits production and how defoliation mitigates that response.

The use of C4 grasses for conservation is also growing as more people are re-introducing native tallgrass prairie species, including C4 grasses, to the landscape. Land managers plant native tallgrass prairie to increase carbon sequestration (Tufekcioglu et al., 1998), improve habitat for birds (Giuliano and Daves, 2002), and/or promote genetic diversity. For many on-farm conservation projects, producers could be eligible for so-called federal or state “green payments” that compensate for the cost of implementing conservation projects and loss of production during the implementation. These producers may not be expecting an increase in production, but would benefit from understanding whether adding C4 grasses to the landscape will cause a loss of production and how management might affect root production, a parameter directly linked to carbon sequestration.

In addition, C4 grasses are of increasing interest as a biofuel source for cellulostic ethanol production (Tilman et al., 2006; Schmer et al., 2008). Irrespective of the motivation for introducing C4 grasses to a system, more information is needed about how management affects production of C3 and C4 grasses. We conducted three single-season greenhouse experiments under 1) spring, 2) summer, and 3) spring+summer clipping regimes. For each experiment, we determined clipping frequency and clipping height effects on above- and belowground net primary production (ANPP and BNPP) and total and seasonal forage availability of *Bromus inermis* Leyss (smooth brome, C3) and *Andropogon gerardii* Vitman (big bluestem, C4)–two grasses often considered for pasture and prairie seeding.

METHODS

Materials and experimental design

We conducted this work in a greenhouse at the West Madison Agricultural Research Station, Madison, WI, USA. We sowed big bluestem, a C4 bunchgrass native to the North American tallgrass prairie, and smooth brome, a sod forming C3 grass common to pastures of North America. Pots were planted on 9 March 2004 in autoclaved 19 L pots (Standard 2000) filled with a mix of 50% field soil and 50% sand. Three centimeters of sterilized soil was applied to the top of each pot to minimize damping off in the seedlings. Big bluestem and smooth brome (Olds Seed Co., Madison WI) was seeded at a rate of ~10 pure live seeds pot^{-1} into the layer of sterilized soil. Throughout the course of the study pots were weeded to remove nonplanted species. In late June and early August, 0.95 L of 20-9-20 (N-P-K) fertilizer (Technigrow by Sunshine) was added to each pot. The greenhouse had an average daytime temperature of 26 °C and nighttime temperature of 18 °C. The average photoperiod was 16 h (6 am to 10 pm). Pots were checked for moisture status daily and watered as needed to saturation.

For each experiment (spring, summer, and spring+summer), we employed a completely randomized, fully factorial experimental design where the two species, two clipping frequency levels (weekly and monthly), two clipping heights (5 cm and 10 cm), and six replicates were randomly assigned to pots. Monthly clipping was meant to mimic the frequency of defoliation applied in rotational grazing systems. Our weekly clipping treatment was an effort to mimic continuous grazing, where livestock distribution in space is not controlled through the season. Clipping treatments were applied with scissors, and clipped biomass was placed in paper bags, dried at 60^{o} C to constant weight, and weighed. Plants in the spring+summer experiment were clipped late May through September. Plants in the spring and summer experiments were clipped from May to mid-July and mid-July to September, respectively. These season of clipping experiments were adjacent to each other in the greenhouse. Because this was a greenhouse experiment with a controlled environment, there were not the extreme differences in temperature, light, and moisture that would be associated with different seasons of grazing in a field setting. We use the terms spring and summer more as a reference to the initiation and duration of clipping in reference to the initial seeding.

We sowed three control pots of each species that received no clipping. At the end of September, all aboveground biomass was harvested to soil level, dried, and weighed for clipped and control plants. In addition, soil was washed away from the root mass, which was dried to a constant weight at 60^{o} C and weighed. This portion included all belowground biomass, i.e., we did not separate roots from crowns.

Statistical Analyses

Clipped dried biomass weights plus the final harvest dry weight were summed for a given pot to calculate ANPP. We estimated BNPP as belowground biomass at the final harvest. Available forage for a given month was calculated as dry biomass for that month's clipping. Total available forage was calculated as the sum of clipped biomass, not including the final harvest. We performed three fully factorial ANOVAs for each experiment for ANPP, BNPP, and total available forage and determined significance at the $\alpha=0.05$ level. When we observed significant interactions with ANOVA, we applied Bonferonni multiple comparison tests to separate means with an experiment-wise error rate of $\alpha=0.05$. Control weights were not part of our ANOVA models, but were used for visual comparisons in figures. For the control pots, two-tailed t-tests were used to test for differences in ANPP and BNPP between the two species.

RESULTS

Aboveground net primary production

There were no significant interactions in any of the experiments, indicating that smooth brome and big bluestem responded similarly to clipping treatments (Table 1). Smooth brome produced more aboveground biomass than big bluestem irrespective of the season of clipping (Fig. 1). Under spring and spring+summer clipping, the grasses produced significantly less biomass under weekly and 5 cm clipping heights (Fig. 1). In contrast, when clipping occurred only during the summer, the clipping treatments had no significant effect on ANPP (Table 1). Clipped smooth brome pots were more similar to unclipped smooth brome controls compared to the differences in ANPP between clipped and unclipped big bluestem (Fig. 1). Average ANPP values for unclipped smooth brome and big bluestem pots were 976 and 729 g m^{-2}, respectively, but were not significantly different ($t[2]=1.145, P=0.28$).

Belowground net primary production

Average BNPP for unclipped smooth brome and big bluestem was significantly different with means of 945 and 434 g m^{-2} ($t[2]=5.72, P=0.03$) respectively, and was higher than clipped pots for both species in all experiments. For plants clipped in the spring and spring+summer, we observed a significant species × clipping height interaction (Table 2): while smooth brome produced less root biomass under the 5 cm clipping height, big bluestem was unaffected by clipping height (Fig. 2). Even with decreased production under this treatment, smooth brome had higher BNPP than big bluestem (Fig. 2). There was a significant clipping frequency effect for both spring and spring+summer clipped pots (Table 2) with monthly clipping resulting in greater BNPP (Fig. 2). Summer-clipped plants behaved differently in that there were no significant treatment interactions (Table 2). Smooth brome had significantly higher BNPP than big bluestem, and BNPP was higher in pots clipped monthly and pots clipped to 10 cm (Fig. 3).

Available forage

Data from the spring+summer clipping experiment was used in the analysis of total available forage. There were three two-way interactions: species × clipping frequency, species × clipping height, and clipping frequency × clipping height (Table 3). Smooth brome always had higher total available forage than big bluestem (Fig. 4.I and 4.II). Clipping frequency did not affect available forage of smooth brome, while weekly clipping resulted in less big bluestem forage (Fig. 4.I). Conversely, clipping height did not affect available forage for big bluestem, while the 5 cm clipping height resulted in more available forage for smooth brome (Fig. 4.II). Averaged across species, clipping frequency only affected plants clipped to 5 cm while clipping height only affected plants clipped monthly (Fig. 4.III).

Because big bluestem never produced more biomass than smooth brome, we examined species differences in seasonal distribution of available forage only where it did best—under monthly clipping for both clipping heights. There were summer months that big bluestem produced more available forage than smooth brome (Fig. 5), especially when clipped to 10 cm.

DISCUSSION

We observed a different response to treatments for two similar metrics: total available forage and ANPP (for pots clipped spring+summer). The significant treatment interactions seen for total available forage indicate that defoliation interval is an important factor for big bluestem but not smooth brome, and that clipping height is an important factor smooth brome but not big bluestem. In contrast, clipping treatments affected ANPP of the species similarly. The difference between these two measurements is that ANPP includes the final harvest of all aboveground biomass while available forage does not. From an agronomic perspective, available forage may be of primary interest while for calculating net ecosystem production (NEP) or carbon budgets, ANPP would be preferred. With the rise in agroecological research, this finding emphasizes the importance in choosing and defining which parameters to measure to address both agronomic and ecological objectives of a study. In addition, it calls for caution in generalizing results from ecological work that is often focused on ANPP and agronomic studies that measure available forage.

Smooth brome produced more aboveground biomass than big bluestem except when plants were not clipped. These results contradict other studies showing greater productivity (Jung et al., 1985; Belesky and Fedders, 1995; but see Smart et al., 1995), less deleterious effects of clipping (Boryslawski and Bentley, 1985), and greater persistence and competitiveness (Belesky, 2006) for C4 compared to C3 grasses. One explanation could be that clipping treatments were initiated a short time after seeding and C4 plants needed more time to establish before defoliation. However, even when clipping was delayed until summer smooth brome produced more than big bluestem. These results indicate that grazing or harvesting could be initiated on C3 pastures sooner than C4 pastures planted at the same time. Other studies have shown that during the first year of growth C4 grasses allocate the majority of their energy to belowground production (Johnson and Matchett, 2001; Camill et al., 2004). Compared to the C3 grass, the C4 grass in our experiment had lower BNPP for both clipped and control plants compared to the C3 grass. These results may differ from previous studies in that water and nutrients were not limiting factors as they can be in outdoor field settings. C4 grasses are more nutrient and water use efficient (Lambers et al., 1998; Long, 1999), and our results may have differed if plants had been grown outdoors without irrigation or nutrient additions (but see Reich et al., 2001). The seasonal distribution of forage availability (Fig. 5) demonstrated that early in the season smooth brome produced more than big bluestem, but after that big bluestem produced equal or greater amounts through the summer. These results are similar to those of Belesky and Fedders (1995), who documented equal or greater dry matter yields of the C4 grass compared to the C3 grass in a temperate environment and C4 growth occurring during the time when C3 growth was low. Unlike their results however, the greater productivity later in the season for the C4 grass in our experiment was not enough to compensate for the initial low production. This may not be of concern to farmers, however, who are often scrambling to manage excess forage in the spring and may prefer less total available forage in the spring for more in the hot summer months (Clapham et al., 2008).

Plants clipped in the summer behaved differently than spring and spring+summer clipped plants for both ANPP and BNPP. Delaying haying or grazing until mid-summer has been suggested for the protection of grassland bird nests (Giuliano and Daves, 2002). Our results would indicate that under this management, variations in grazing frequency and clipping heights would not affect ANPP, but BNPP would be greater under monthly clipping and a 10 cm clipping height. Belowground production of smooth brome, but not big bluestem, was affected by clipping height for spring and spring+summer clipping. Guitian and Bardgett (2000) showed defoliation effects on root production to differ by species based on grazing tolerance. Defoliation negatively affected root production for grazing tolerant grass species but not for a grass species with low grazing tolerance. While our results differ in that defoliation negatively affected root production for both species, the clipping height treatment only affected BNPP of smooth brome. These management effects on BNPP could have important ramifications for carbon sequestration in grasslands, increasingly of interest to producers, researchers, policymakers, and investors (Follett et al., 2001). Roots are the main source of organic carbon to grassland soils (Dormaar, 1992; Titlyanova et al., 1999), and we have great opportunity to influence carbon sequestration by manipulation of the crop root system (Rees et al., 2005). The productivity and expansive root systems of C4 grasses have been promoted in this regard and currently federal programs and market-based incentives are being developed to pay farmers for the land they have in grassland for their role in carbon sequestration. Our results suggest that management will have differing effects depending on when harvesting or grazing is initiated. Other work has shown that less intense (i.e., >10 cm clipping height) and/or less frequent (i.e., >40 day recovery period) defoliation may promote persistence of big bluestem (Mousel et al., 2003; Mousel et al., 2005), something we could not measure in a one-season greenhouse experiment. More work is needed to test these defoliation treatments under field conditions and with more species of C4 and C3 grasses.

For plants clipped in the spring and spring+summer, ANPP was higher under monthly clipping. In this experiment, monthly clipping was meant to mimic rotational grazing and weekly clipping to mimic a continuous grazing system. Our results are similar to others showing greater production under rotational vs. continuous grazing (Paine et al., 1999). When clipping occurred in the spring and spring+summer, ANPP was higher under the 10 than 5 cm clipping height. It is well documented that frequent and intense defoliation is deleterious to smooth brome production and that yields and persistence can be greater if defoliation occurs before culm elongation or well after heading (see Casler, 2004 for references). We noted that smooth brome plants were heading out before the first defoliation event. There are equivocal results on the general effect of residual height on C3 grass production, in part due to differing species, defoliation heights and intervals, and environmental conditions of experiments (Volesky and Anderson, 2007). Generally, for areas with more than 700 mm of precipitation a year, grazing can have mild negative or positive effects on ANPP, but the effect is more frequently negative (Oesterheld et al., 1999). Compared to grassland ecosystem responses to defoliation, at the plant level (comparable to our greenhouse experiment) defoliation more frequently causes negative effects and reduces production by a greater percentage (Ferraro and Oesterheld, 2002). Therefore, less severe reductions in production might be expected under similar defoliation regimes in a field setting. Leaving more residual for C4 grasses is commonly advised (Anderson, 2000). Our results indicate that this is beneficial for both species for aboveground biomass production when clipping is initiated early in the growing season.

The initiation of clipping 2.5 months after seeding was similar to or greater than other greenhouse clipping experiments (Boryslawski and Bentley, 1985; del-Val and Crawley, 2004). However, a key difference in greenhouse experiments and field settings may be the time allowed for plants to establish before defoliation begins. Many field experiments evaluating defoliation effects initiated grazing or clipping 12 or more months following seeding (Posler et al., 1993; Moore et al., 2004; Belesky, 2006; Volesky and Anderson, 2007), resulting in older plants that may have better developed storage organs at the time of grazing. Therefore, it might be expected that the effects of grazing would be less deleterious on these more established plants; however, plants in the field are also exposed to more competition from the pasture community, variations in precipitation and temperature, belowground herbivory, and other stresses that could weaken the vigor and resilience of these plants to repeated defoliation. In addition, there is little published information available to farmers indicating the time interval needed between seeding a pasture and initiation of grazing or clipping. Published extension materials usually indicate an ideal plant height to graze (Sullivan et al., 2000; Blanchet et al., 2003), but do not comment on time needed for plants to develop storage organs. General recommendations from grazing specialists are to wait until July or August if spring seeding has occurred (L. Paine, personal communication, 2007), which is similar to our 2.5 month period, and C4 grass production for biofuels can include harvest during the establishment year (Schmer et al., 2008). Few temperate grazed pastures are pure monocultures, and selective foraging by herbivores of certain grass species, or even clones of a given grass (Falkner and Casler, 1998), could result in different results from what we found. Future research should test these treatments under field conditions, perhaps with a greater diversity of grass species under various grazing regimes.

CONCLUDING REMARKS

The results of these clipping studies shed light on both specific management effects and issues relating to grassland research. In all experiments, ANPP and BNPP of smooth brome was greater than big bluestem, although during some hot summer months big bluestem produced more available forage than smooth brome. Clipping effects on ANPP and BNPP were different for summer clipped pots than for spring and spring+summer pots, indicating that management could be tailored to meet specific agronomic or conservation goals. We found different effects of management on two similar metrics: total available forage and ANPP. This has important ramifications for our ability to generalize about the effects of management from ecological and agronomic grassland studies.

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TABLES

TABLE 1. ANOVA results for aboveground net primary production for the three clipping experiments. DF for each factor was 1.

Factor	F Value	Pr (F)
Spring + summer		
Species	193.68	<0.01
Clipping frequency	25.43	<0.01
Clipping height	10.17	<0.01
Species x frequency	2.26	0.14
Species x clipping height	0.10	0.75
Clipping frequency x clipping height	2.29	0.14
Species x clipping frequency x clipping height	<0.01	0.98
Spring		
Species	106.46	<0.01
Clipping frequency	14.57	<0.01
Clipping height	8.12	0.01
Species x frequency	0.07	0.79
Species x clipping height	0.16	0.69
Clipping frequency x clipping height	<0.01	0.95
Species x clipping frequency x clipping height	<0.01	0.98
Summer		
Species	60.54	<0.01
Clipping frequency	0.75	0.39
Clipping height	0.44	0.51
Species x frequency	0.04	0.85
Species x clipping height	<0.01	0.98
Clipping frequency x clipping height	0.01	0.92
Species x clipping frequency x clipping height	0.71	0.40

TABLE 2. ANOVA results for belowground net primary production for the three clipping experiments. DF for each factor was 1.

	Factor	F Value	Pr (F)
Spring + summer			
	Species	310.11	<0.01
	Clipping frequency	38.45	<0.01
	Clipping height	32.85	<0.01
	Species x frequency	4.28	0.05
	Species x clipping height	16.81	<0.01
	Clipping frequency x clipping height	3.47	0.07
	Species x clipping frequency x clipping height	0.28	0.60
Spring			
	Species	259.47	<0.01
	Clipping frequency	12.38	<0.01
	Clipping height	35.32	<0.01
	Species x frequency	0.90	0.35
	Species x clipping height	22.29	<0.01
	Clipping frequency x clipping height	0.19	0.66
	Species x clipping frequency x clipping height	0.43	0.52
Summer			
	Species	112.01	<0.01
	Clipping frequency	4.81	0.04
	Clipping height	4.34	0.04
	Species x frequency	0.87	0.36
	Species x clipping height	3.16	0.08
	Clipping frequency x clipping height	<0.00	0.99
	Species x clipping frequency x clipping height	0.75	0.39

TABLE 3. ANOVA results for total available forage for pots clipped spring + summer. DF for each factor was 1.

Factor	**F Value**	**Pr (F)**
Species	46.73	<0.01
Clipping frequency	18.86	<0.01
Clipping height	2.47	0.12
Species x frequency	4.62	0.04
Species x clipping height	9.66	<0.01
Clipping frequency x clipping height	4.56	0.04
Species x clipping frequency x clipping height	0.16	0.69

FIGURES

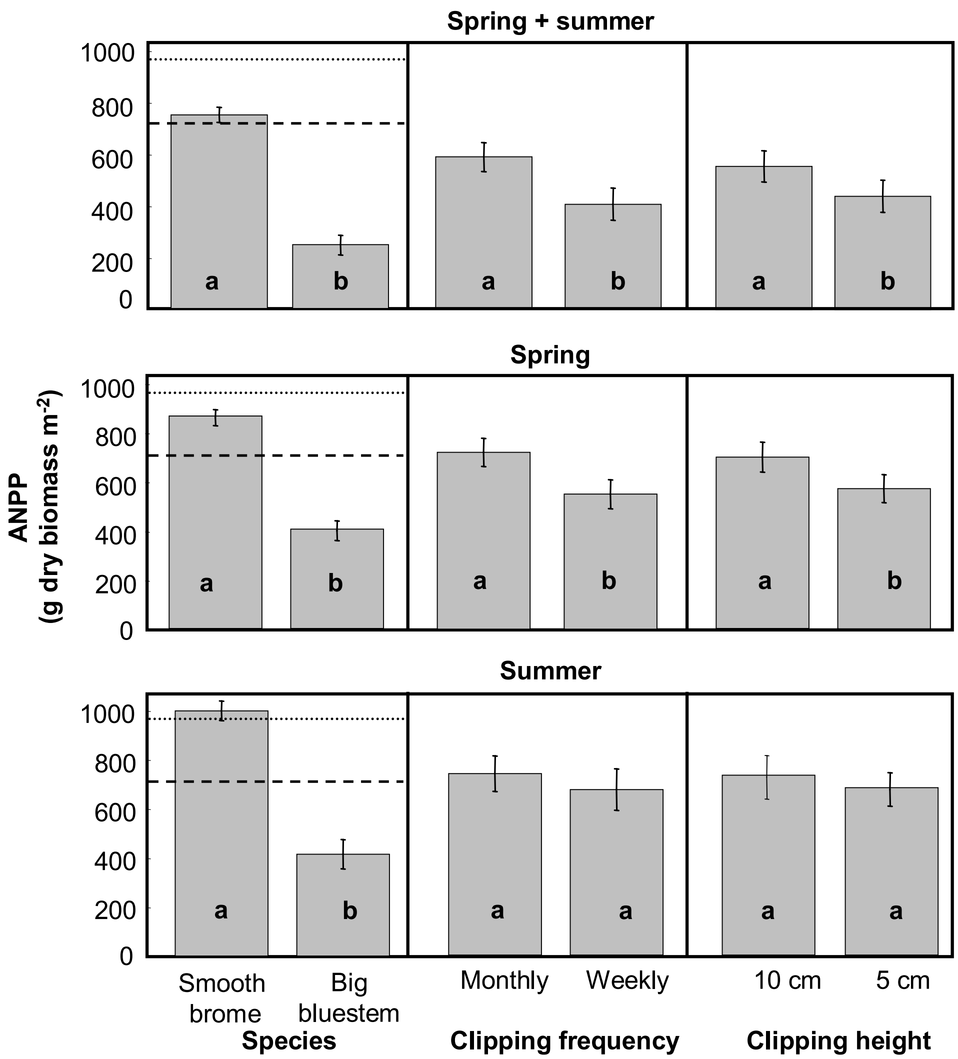

FIGURE 1. Aboveground net primary production (ANPP, mean ± one SE, n=6) for spring + summer, spring, and summer clipping experiments. Within each plot, bars labeled with different letters are significantly different (P<0.05). There were no significant interactions. Average ANPP for unclipped controls indicated for smooth brome (dotted line) and big bluestem (dashed line).

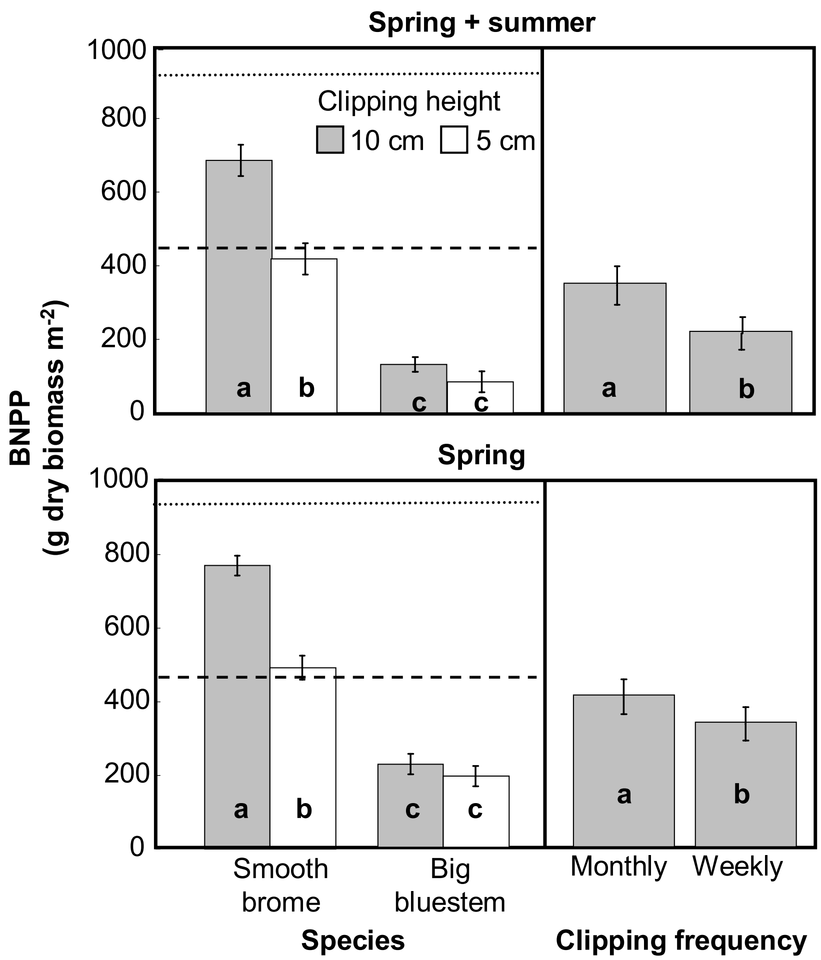

FIGURE 2. Belowground net primary production (BNPP, mean ± one SE, n=6) for plants clipped spring+ summer and spring. Average BNPP for unclipped controls indicated for smooth brome (dotted line) and big bluestem (dashed line). There was a significant (P<0.05) species × clipping height interaction for spring+summer and spring experiments. Within each plot, bars with different letters are significantly different (P<0.05).

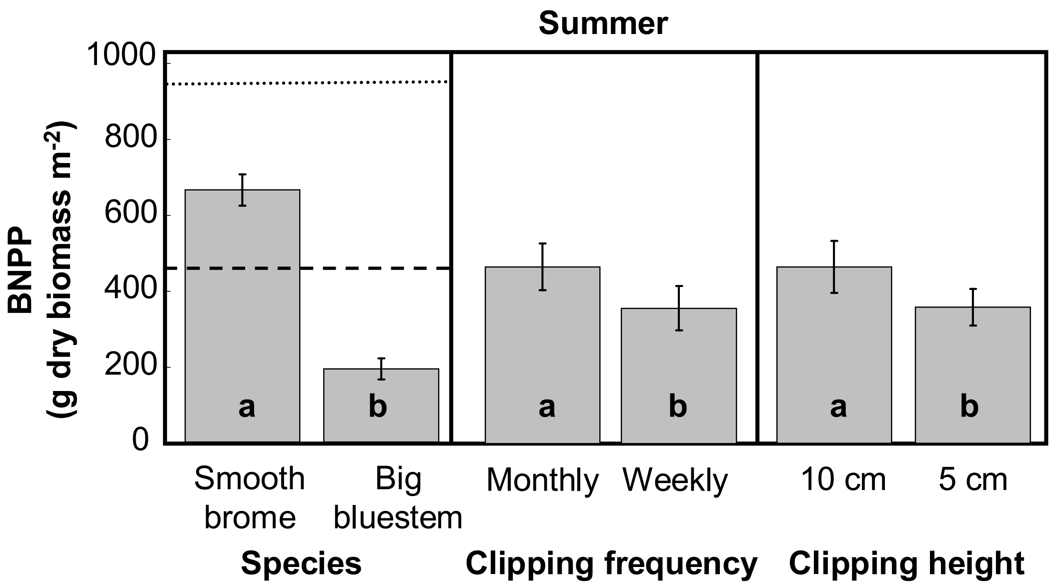

FIGURE 3. Belowground net primary production (BNPP, mean ± one SE, n=6) under summer clipping. Average BNPP for unclipped controls indicated for smooth brome (dotted line) and big bluestem (dashed line). Within each plot, bars with different letters are significantly different (*P*<0.05). There were no significant interactions.

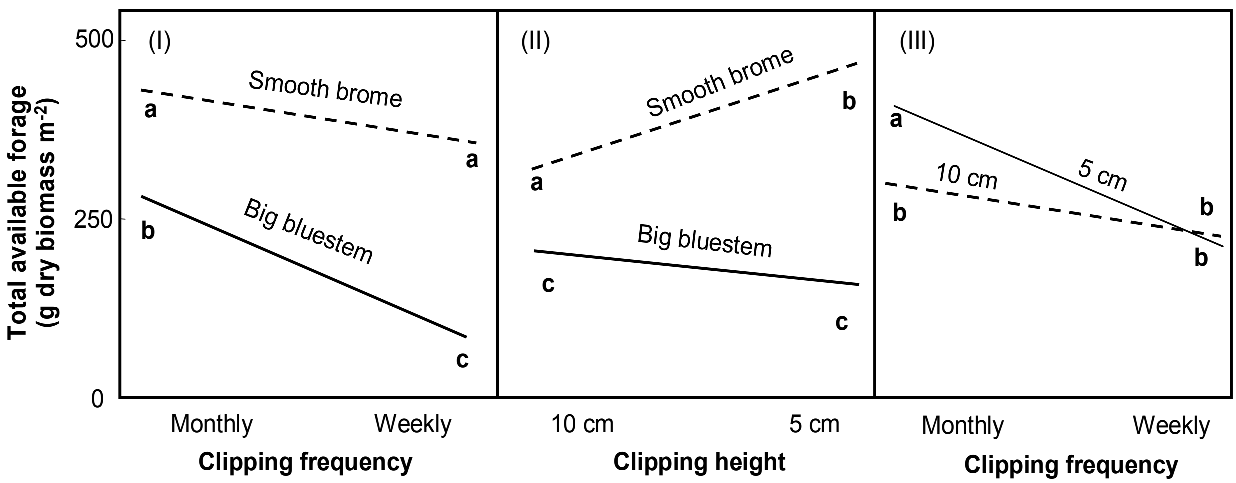

FIGURE 4. Interaction plots for total available forage for pots clipped spring+summer (mean, n=6). (I) Smooth brome was not affected by clipping frequency while big bluestem had less forage under weekly clipping. (II) Clipping height affected production of smooth brome but not big bluestem. (III) Clipping frequency affected plants clipped to 5 cm but not to 10 cm. Plants clipped monthly were affected by clipping height while plants clipped weekly were not. Within each plot, different letters indicate significantly different means ($P<0.05$).

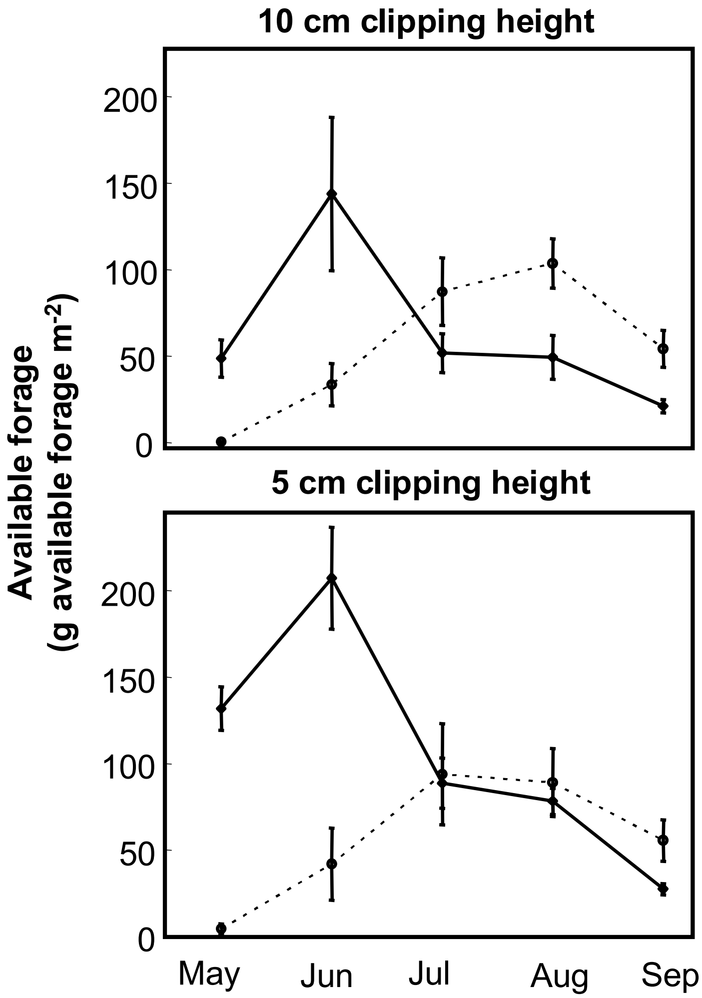

FIGURE 5. Monthly available forage (mean ± one SE, n=6) for smooth brome (solid line) and big bluestem (dashed line) clipped monthly.

GENERAL CONCLUSION

The agroecological framework of our research—with social, ecological, and agronomic components—strengthened our work by helping us to generate results that inform plant ecology theory and management while bridging the gap between disciplines. However, unique challenges did present themselves to us, which will be seen as we discuss the insights gained from taking this approach.

Increasingly ecologists are seen as friends or advisors to the farmer, but these stakeholders often have different timetables. Farmers operate on an annual basis in order to meet their financial needs whereas ecologists are often oriented towards long-term research. For example, from an ecological perspective, three years may not constitute a long-term study of the establishment and coexistence of C3 and C4 grasses; but from a farmer's perspective, three years may be a long period to manage for this coexistence. Farmers are excited about caring for the land, and we were continually impressed by the interest in and appreciation of our research, as expressed to us during field days and farmer meetings. However, they have concerns about the financial bottom line, and more research is needed to find restoration and conservation projects for agricultural lands that have positive financial outcomes in the short term.

We found the use of the analytical tools and theories of ecology useful for manipulating and understanding agricultural systems. For example, ordination and regression tree analyses—both used to analyze complex ecological data—allowed us to discover patterns in the plant community data that helped to inform pasture management; and due to the ecological objective to measure net primary production, we were able to show how production-oriented management (nitrogen addition) can have negative effects on root production. However, we acknowledge the varying *success thresholds* of ecological and agricultural work. From an ecological perspective, increasing plant diversity per se was achieved, but from a farmer's view, the level of native grass recruitment may not be sufficient under some treatments. Likewise, results from the carbon amendment treatment informed plant ecology theory and highlighted future research needs—a success. But from a farmer's perspective, it was a failed treatment as carbon application requires monetary and labor inputs but limited native grass growth compared to not applying a soil amendment.

By including a social component, obstacles to the use of native grasses in grazing systems were identified, e.g., farmer unfamiliarity with native grass species, but social research is complex and can be quite expensive. We learned very quickly that designing a survey instrument is just as, or even more, complicated than designing an experimental layout for field research. And being in-between major disciplines, it is difficult to secure funding and publication outlets: in response to one proposal we had written, we were told that "these pastures aren't plant communities." Likewise, restoration-oriented funders have been hesitant to support projects in agricultural lands.

This agroecological framework allows us to target gaps in current research and to better understand agroecosystems as a whole. There are challenges associated with taking this approach, and more discussion is needed to address them as we move forward. We believe interdisciplinary work can foster dynamic research and collaboration on a broad scale, while providing farmers with specific information pertaining to agroecosystem management.

Appendix 1. Survey cover letter and questionnaire

Date
Name/Address

Dear

I am writing to ask your help in a study of Wisconsin graziers being conducted as part of my graduate research. This study is part of an effort to learn more about grazier opinions on conservation projects and the use of native prairie grasses in pastures.

Your household is one of the small number in which people are being asked to give their opinion on these matters. It was drawn randomly from the Grass Works Inc. mailing list.

Results from the survey will be used to help researchers, agency personnel and policymakers develop more directed conservation policy and more focused agroecosystem research. This information will help develop conservation-production oriented projects that are needed and realistic. I am asking for your participation because the only way we can find out the needs and perception of graziers relating to conservation issues is to ask you.

Your answers are completely confidential and will be released only as summaries in which no individual's answers can be identified. This survey is voluntary. However, you can help us very much by taking a few minutes to share your experiences and opinions about conservation issues. If for some reason you prefer not to respond, then please let us know by returning the blank questionnaire in the stamped envelope.

We ask that the primary farm operator complete the survey. For our purposes, this is the person who is most actively involved in the day-to-day management, decision-making, and work on the farm. When finished, please fold the survey in half and return it in the postage-paid return envelope.

If you have any questions or comments about this study, I would be happy to talk with you. You can contact me at my office number 608-890-0268, by e-mail (jedoll@wisc.edu), or at the address below. You may also contact Kristin Zache at the University of Wisconsin Survey Center at 265-4064 or toll free, at 1-800-291-8624.

Thank you very much for helping with this important study!

Sincerely,

Julie E. Doll, Graduate Research Assistant
UW – Madison, Grassland Ecology Lab

Wisconsin Graziers and Conservation Study

THE UNIVERSITY *of* WISCONSIN MADISON

Thank you for taking the time to help us with this important project! Your answers are completely confidential and will never be linked to your name or any other identifying information.

1. Do you rely on pastures for at least part of the forage ration of your livestock?

☐ Yes → Continue

☐ No → Stop here and please return the survey, so that we can check your name off of the mailing list. That will help us a great deal!

Conservation Projects

2. A "conservation project" is *any management practice or project you adopt to conserve or enhance resources and the environment on your farm, either by yourself or with outside help.* Which of the following conservation projects have you used on your farm? *Check all that apply.*

☐ CRP (Conservation Reserve Program)
☐ Conservation tillage
☐ Riparian buffer strips
☐ Trees for windbreaks
☐ Wetland restoration
☐ No-till
☐ Soil testing to reduce fertilizer inputs
☐ Wildlife habitat improvement
☐ Contour planting
☐ Other; please specify: ____________________

3. How much do you agree or disagree with each statement? *Check one box per statement.*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
Having conservation projects on my farm is important to me.	☐	☐	☐	☐	☐
I spend/have spent a considerable amount of money on implementing and maintaining conservation projects on my farm.	☐	☐	☐	☐	☐
I am satisfied with my current conservation projects.	☐	☐	☐	☐	☐
I want to have more conservation projects on my farm.	☐	☐	☐	☐	☐
I think my current conservation projects benefit the environment.	☐	☐	☐	☐	☐

4. Below are several factors that are considered when a farmer makes decisions about implementing conservation projects. Please rate how important or unimportant each factor is to you when considering the implementation of conservation projects. *Check one box per statement.*

	Very Unimportant	Somewhat Unimportant	Somewhat Important	Very Important
Cost to implement conservation projects	☐	☐	☐	☐
Cost to maintain conservation projects	☐	☐	☐	☐
Amount of government cost-sharing available for projects	☐	☐	☐	☐
Amount of government technical assistance available for projects	☐	☐	☐	☐
Demonstrated profitability of conservation projects	☐	☐	☐	☐
The disruption in farming operations in order to implement the conservation projects	☐	☐	☐	☐
Potential loss of production associated with adopting conservation projects	☐	☐	☐	☐
Amount of time to implement conservation projects	☐	☐	☐	☐
Amount of time to maintain conservation projects	☐	☐	☐	☐
Necessity to acquire new skills to implement and maintain the conservation projects	☐	☐	☐	☐
Availability of information on the conservation projects	☐	☐	☐	☐
Potential of projects to conserve/ improve resources	☐	☐	☐	☐
Potential of projects to protect the environment	☐	☐	☐	☐
Potential of projects to improve wildlife habitat	☐	☐	☐	☐
Potential of projects to beautify farm	☐	☐	☐	☐
Potential to improve quality of life	☐	☐	☐	☐
Potential of projects to ease labor in working the land	☐	☐	☐	☐
Ability to implement projects with little outside assistance	☐	☐	☐	☐
The need to work with any agency personnel to implement projects	☐	☐	☐	☐
Restrictions agencies impose as the price of receiving cost-sharing	☐	☐	☐	☐
Reaction of neighbors	☐	☐	☐	☐
Reaction of future buyers/renters of land	☐	☐	☐	☐

5. Is there anything else that we have not yet mentioned that you find important to consider when deciding about implementing conservation projects? *Please explain.*

____

____

Native Prairie Grasses

6. The next questions are about native prairie grasses. We would like to know if you use *native prairie grasses* in your grazing system and why or why not. By native prairie grass we mean those *species present in the tall-grass prairies that covered many parts of the Midwestern United States before European settlement*. These grasses include, but are not limited to, big bluestem (turkey-foot), Indiangrass, and switchgrass. Do you have native prairie grasses on your farm?

☐ Yes → Continue

☐ No → Skip to Question 17

☐ Don't Know → Skip to Question 17

7. Approximately how many acres of native prairie grasses are on your farm?

______________ **acres**

8. Did you establish any of these native prairie grasses?

☐ Yes → Continue

☐ No → Skip to Question 15

9. Approximately how many acres of native grasses did you plant?

______________ **acres**

10. Why did you plant native grasses on your farm? *Check all that apply.*

☐ Landscaping/Beauty

☐ Forage for livestock

☐ Conservation

☐ CRP (Conservation Reserve Program)

☐ Other; please specify: ____

11. Did you receive financial assistance to establish the native grasses?

☐ Yes → **Who provided this assistance?** ______________

☐ No

12. Did you receive technical assistance to establish the native grasses?

☐ Yes → **Who provided this assistance?** ________________

☐ No

13. Do you know which native grasses you planted?

☐ Yes → **Please list the native prairie grasses you planted.**

____

☐ No

14. What were the biggest challenges to implementing native grasses into your system?

____

____

15. Have livestock grazed any of the native grass areas?

☐ Yes

☐ No → Skip to Question 17

16. Do you know which grasses did well under grazing?

☐ Yes → **Which grasses did well under grazing?** ________________

☐ No

17. Do you know someone who uses native prairie grasses in their grazed pastures?

☐ Yes

☐ No

18. Are you aware of programs or aid to help with the cost of planting native prairie grasses on your farm?

☐ Yes

☐ No

19. Would you need technical assistance to plant native prairie grasses on your farm?

☐ Yes

☐ No

20. Do you know where you can buy native prairie grass seed?

☐ Yes

☐ No

21. Please indicate how much you agree or disagree with each of the following statements. *Check one box for each statement.*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
I find it easy to identify native prairie grass species.	☐	☐	☐	☐	☐
I am interested in having native prairie grasses as a part of my grazing system.	☐	☐	☐	☐	☐
I think native prairie grasses could benefit the environment.	☐	☐	☐	☐	☐
I would use native prairie grass species for livestock forage.	☐	☐	☐	☐	☐

22. Please indicate how likely or unlikely you think having native grasses in your GRAZED pastures will result in each of the following.

	Very Unlikely	Somewhat Unlikely	Neither Likely nor Unlikely	Somewhat Likely	Very Likely
Improved soil conditions	☐	☐	☐	☐	☐
Improved environmental conditions	☐	☐	☐	☐	☐
Improved wildlife habitat	☐	☐	☐	☐	☐
Lower overall pasture production	☐	☐	☐	☐	☐
Higher overall pasture production	☐	☐	☐	☐	☐
Better forage yields under adverse weather conditions	☐	☐	☐	☐	☐
Lower forage quality	☐	☐	☐	☐	☐
Higher forage quality	☐	☐	☐	☐	☐
Healthier livestock	☐	☐	☐	☐	☐
More labor requirements	☐	☐	☐	☐	☐
More financial risk	☐	☐	☐	☐	☐
A longer establishment period	☐	☐	☐	☐	☐
Better quality of life for you and your family	☐	☐	☐	☐	☐
Improved perception of your farming practices from society	☐	☐	☐	☐	☐

23. Is there anything else that we have not yet mentioned that is important to consider when deciding about using native grasses in grazed pastures? *Please explain.*

____

____

Demographics

Finally, we need to ask standard demographic questions for data analysis purposes only.

24. In what county is your farm located? _______________

25. What is the age of the primary operator? _______________

26. What is your sex? ☐ Male ☐ Female

27. What is the last grade you have completed in school?

- ☐ I did not finish eighth grade
- ☐ Completed eighth grade
- ☐ Some high school
- ☐ High School diploma
- ☐ Some college, trade school, or apprenticeship
- ☐ A.A. degree or at least two years of college
- ☐ B.S. or B.A. degree
- ☐ Some postgraduate work
- ☐ Advanced degree, such as M.S., M.D. or Ph.D.

28. How many total years have you been farming? _______________ years

29. Please check the response that best describes how land on this farm will be used when the present land owner will no longer operate this farm.

- ☐ Land will be operated by children of the present land owner.
- ☐ Land will be operated by a tenant for children of the present land owner.
- ☐ Land will be sold to a non-family member for development purposes.
- ☐ Land will be sold to another farmer and remain in production agriculture.
- ☐ Land will be purchased and operated by a family member other than owner's children.
- ☐ Other; Please specify: ____
- ☐ Future of farm is unknown.

30. Which of the following categories comes closest to your <u>total annual family income</u>, before taxes, for 2005? Total family income includes your family's share of net farm income <u>plus</u> income of household members from other sources. Please consider things such as sale of farm products, rent payments from another farmer, and rent payments or pension from the government into total family income. <u>Do not</u> include health insurance or value of farm assets.

- ☐ Less than $5,000
- ☐ $5,000 to $9,999
- ☐ $10,000 to $19,999
- ☐ $20,000 to $34,999
- ☐ $35,000 to $49,999
- ☐ $50,000 to $74,999
- ☐ $75,000 to $99,999
- ☐ $100,000 to $149,999
- ☐ $150,000 to $199,999
- ☐ $200,000 or more

31. What percentage of your total 2005 family income was from the farm? *Check one.*

☐ Less than 10%
☐ 10% to 25%
☐ 26% to 50%
☐ 51% to 75%
☐ 76% to 100%

32. Approximately how many farmed acres do you currently own and rent?

_______________ acres **owned**
_______________ acres **rented**

33. How many <u>total acres</u> of the following do you own and rent?

_______ pastures used for rotational grazing
_______ pastures used for continuous grazing
_______ annual crop production
_______ acres in set-aside, CRP or buffers
_______ other; please specify: ________________________
_______ hay fields
_______ woodlands
_______ wetlands
_______ acres for homestead/buildings

34. On average in 2005, how many of the following animals were on your farm?

Dairy cattle, including heifers and young stock: _______
Beef cattle, including young stock: _______
Bison: _______
Goats: _______
Sheep: _______
Hogs: _______
Poultry: _______

35. Are pastures the primary source of total feed for your animals during the grazing months?

☐ Yes
☐ No

36. Do your grazing animals graze continuously on only one paddock or field?

☐ Yes→ Skip to Question 39
☐ No

37. Do you usually move your grazing animals to a new paddock at least once a week?

☐ Yes
☐ No

38. Do you usually rest each paddock at least three weeks between each grazing cycle?

☐ Yes

☐ No

39. Do you belong to an environmental or conservation organization(s)?

☐ Yes → **If yes, then to which do you belong? ______________________________**

☐ No

40. Do you belong to an agricultural organization(s)?

☐ Yes → **If yes, then to which do you belong? ______________________________**

☐ No

***Thank you** for taking the time to complete this questionnaire! Your assistance in providing this information is very appreciated. Please fold the completed questionnaire in half and return it in the postage-paid envelope provided to:*

The UW Survey Center
630 West Mifflin St, RmB174
Madison, WI 53703-2636

If there is anything else that you would like to tell us , please do so in the space provided below:

____

____

____

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____

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____

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____