EFFECTS OF PHOSPHORUS AND NITROGEN MANIPULATIONS ON TALLGRASS PRAIRIE RESTORATION

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Key Words

Tallgrass prairie, restoration, nitrogen, phosphorus, big bluestem, Indian grass

The tallgrass prairie biome of North America once extended from Canada to the Gulf of Mexico. Only an estimated 1% of this important ecosystem remains today (Diamond and Smeins 1988; Samson and Knopf 1994), and these remnant prairie tracts are currently the focus of intense restoration and conservation efforts (Bock and Bock 1995; Kindscher and Tieszen 1998). In addition, conservationists have a very strong interest in restoring native tallgrass prairie communities in abandoned farmland tracts that are being allowed to revert to natural vegetation. A variety of prairie restoration methods are currently in use to achieve these goals, including the careful application of controlled fires, watering, re-seeding with native species, and the differential conditioning of grasses and forbs (Schramm 1990; Thompson 1992).

Soil nutrient availability also plays an important role in the establishment and maintenance of native tallgrass prairie vegetation. The tallgrass prairie environment is characterized by high incident light availability, low nitrogen availability, and seasonal water stress, particularly after fire; these conditions favor C4 grasses, which have higher light-saturated rates of photosynthesis, lower water requirements, and lower N requirements (Turner and Knapp 1996). The growth and nutrient uptake by highly desirable native C_4 grasses such as big bluestem *(Andropogon gerardi* Vitman) and Indian grass *(Sorghastrum nutans (L.)* Nash) tends to perpetuate strong nitrogen-limited conditions, under which they are superior resource competitors (Wedin and Tilman 1990b; Tilman and Wedin 1991).

Native warm-season grasses tend to lose their competitive advantage when soil nitrogen availability is increased (Tilman and Wedin 1991). When soil nutrient cycling in tallgrass prairies is altered by nitrogen fertilization, a decline in the relative biomass of native grasses typically occurs within several years.This change is accompanied by an increase in the relative biomass of weedy forbs, cool-season grasses, and non-native species (Mader 1956; Huffine and Elder 1960; Drawe and Box 1975; Owensby 1969; Owensby and Smith 1979; Wedin and Tilman 1990a,b). Alterations in nitrogen cycling in tallgrass prairie ecosystems due to increasingly high rates of atmospheric nitrogen deposition thus may be a significant threat to the establishment and maintenance of these important systems (Wedin and Tilman 1990a,1996). In the state of Iowa, for example, concentrations of total nitrogen in rainfall currently may exceed 2 mg N/L Q.A. Downing, Iowa State University, pers. comm.).

Selective manipulations of soil nutrient availability potentially represent a powerful new prairie restoration tool. For example, Morgan (1996) has successfully demonstrated the utility of using organic carbon amendments to deplete the soil system of inorganic nitrogen and facilitate the establishment of native grasses in the prairie provinces of Canada. Furthermore, prairie plant species composition changes significantly in response to phosphorus fertilization (Black 1968; Mason and Miltimore 1972; Wight and Black 1972). Although the mechanisms responsible for this plant community response are still not yet completely understood, it is well known that the relative supplies of phosphorus and nitrogen in the soil strongly influence the nutrient limitation status of the plants. Additions of phosphorus increase soil P availability, and thus should intensify the degree of plant nitrogen limitation. The resulting ecological conditions would be predicted to favor the success of strong nitrogen competitors such as big bluestem and Indian grass. The goal of this study was to explore the effects of experimental nitrogen and phosphorus manipulations on the establishment success of these two native bunchgrass species within replanted tallgrass prairie plots located near Lawrence, Kansas. The data reported here were obtained from a series of experimental 16 m^2 (172.8 ft^2) plots similar to those used by David Tilman and co-workers at the Cedar Creek Natural History Area of the University of Minnesota (Tilman 1987).

MATERIALS AND METHODS

In spring 1996, an experimental nitrogen availability gradient was established at an old field site at the University of Kansas' Nelson Environmental Study Area, located northwest of Lawrence, KS. This area was tilled to remove existing vegetation, and the natural seed bank was supplemented with seeds from four dominant native prairie grasses (big bluestem, little bluestem, Indian grass, and switch grass), and two native forbs (Illinois bundleflower and prairie coneflower). These seeds were generously provided by Dr. Kelly Kindscher of the Kansas Biological Survey.

In 1996, the initial design of this study involved the creation of 54, four meter by four meter (13 ft by 13 ft) plots that received nine different nitrogen treatment levels, in sextuplicate. These nitrogen availability treatments included two levels of nitrogen depletion, D1 and D2, which were accomplished using surface soil additions of mixed hardwood and softwood sawdust from a local sawmill (D1=31.25 g m^{-2} yrl; D2=62.50 g m^{-2} yr^{-1}); a set of controls, C, which received neither sawdust nor nitrogen additions; and nitrogen enrichment levels N1N6, which received six different supply rates of surface-applied commercial 34-0-0 ammonium nitrate fertilizer (N1=1.0 g m^{-2} yrl; N2=2.0 g m^{-2} yr^{1}; N3=3.4 g m^{-2} yr^{-1}; N4=5.4 g m^{-2} yr^{1}; N5=7.5 gm^{-2} yr^{1}; N6=9.5 g m^{-2} yr^{1}).

During the first year of the study, measurements of initial soil chemistry at this site performed by the Kansas State University soils testing laboratory revealed that both nitrate-nitrogen and Bray phosphorus concentrations were near growth-limiting levels, based upon established agronomic criteria. In order to increase the degree of N-limitation in half of the experimental units, three plots from each of the 9 nitrogen availability treatments were randomly selected in spring 1997. Since 1997, these 3 plots (at each N supply level) have also received an additional 11.25 g m^{-2} yr^{1} of surface-supplied commercial 0-0-18 superphosphate (P205) fertilizer. The P additions were intended to double the 1996 levels of soil Bray P, and were designated as N+P treatments; the remaining three plots at each of the nine nitrogen availability levels received no phosphorus enrichment, and were designated as N alone treatments.

In addition to the nutrient manipulations above, the 54 plots have been burned annually in the mid-spring of each year since 1996 to remove standing dead vegetation, prevent the invasion of woody shrubs, and inhibit the growth of cool-season species that initiate their growth early in the growing season. Controlled burns also tend to significantly reduce soil nitrogen availability (Seastedt and others 1991) by volatilizing a significant portion of the tissue nitrogen that is present in the dead vegetation and surface litter layer.

In June July 2001, the 54 plots were subsampled in order to examine the effects of N and P fertilization on the ecological success of native bunchgrasses. A complete census of each *Andropogon* or *Sorghastrum* colony was made in each of twelve randomly selected plots, and each bunchgrass colony was individually marked with a forestry flag. The total number of bunchgrass colonies (Bunchgrass Number, colonies per plot) was used as a primary response variable in this analysis. The diameter at soil level of each individual bunchgrass colony was then measured, and the basal area of each colony was calculated. The sum of *Andropogon* + *Sorghartrum* basal area was then calculated for each of the 12 plots, and the proportion of the total area that was occupied at the soil level by these two species in each plot (Percent Bunchgrass Cover) was used as an additional response variable. Statistical analyses of these data were performed with the SYSTAT statistical software (SPSS 2000).

RESULTS AND DISCUSSION

Our results revealed a marked effect of phosphorus availability on the response of the two native tallgrass prairie bunchgrasses to a strong nitrogen supply gradient. In the seven subsampled plots that received only manipulations of nitrogen availability (N alone), no significant pattern was evident in the response of prairie grasses to the N supply gradient, either as the number of bunchgrass colonies present, or as percent basal cover (Figure 1). The Percent Bunchgrass Cover for the native tallgrass species never exceeded 13% in these seven plots, and there was no indication that this response variable changed consistently with alterations in the supply of available nitrogen. In contrast, data from the five subsampled plots receiving manipulations of both nitrogen and phosphorus (N+P) revealed a highly significant decrease in both Bunchgrass Number and Percent Bunchgrass Cover of these species along the nitrogen availability gradient (Figure 2). These results strongly suggest that soil phosphorus can mediate the effects of variations in soil N supply on the abundance of these native prairie grasses.

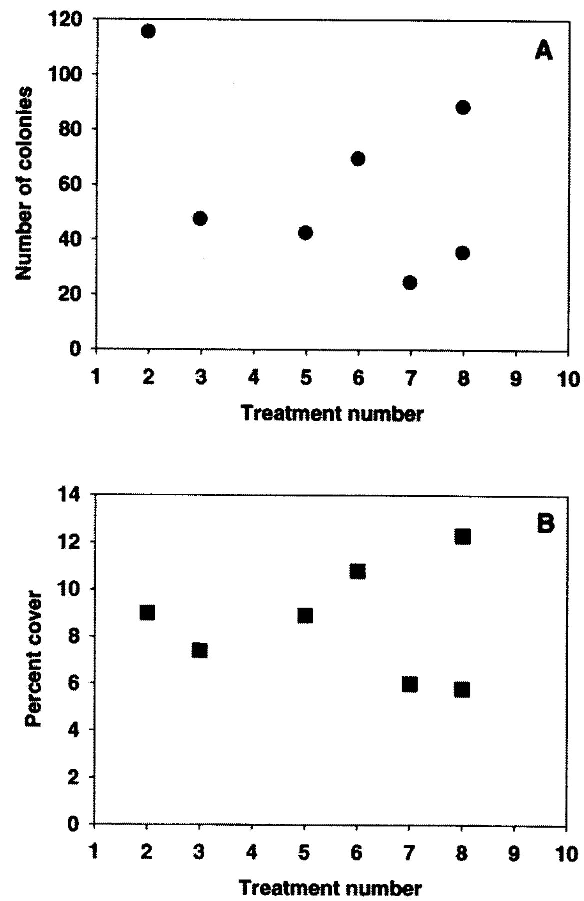

Figure 1. Response of (A) Bunchgrass Number and (B) Bunchgrass Percent Cover to an experimental nitrogen supply gradient in plots receiving nitrogen fertilization alone. The nitrogen supply treatment numbers are 1=D2; 2=D1; 3=C; 4=N1; 5=N2; 6=N3; 7=N4; 8=N5; and 9=N6 (see text). No significant relationship between either response variable and the N supply gradient is evident.

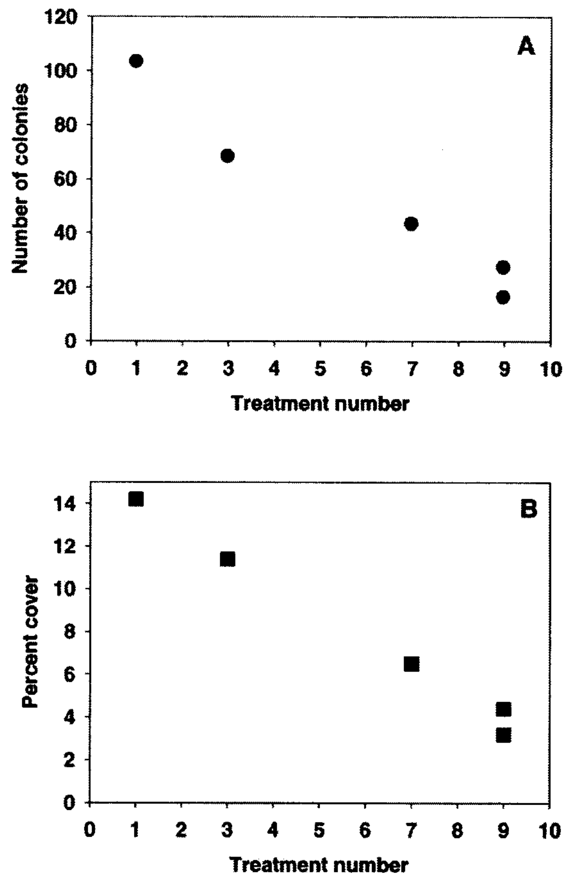

Figure 2. Response of (A) Bunchgrass Number and (B) Bunchgrass Percent Cover to an experimental nitrogen supply gradient in plots receiving both nitrogen and phosphorus fertilization. The nitrogen supply treatment numbers are 1=D2; 2=D1; 3=C; 4=N1; 5=N2; 6=N3; 7=N4; 8=N5; and 9=N6 (see text). Both inverse relationships are highly significant (P < 0.05, Spearman Rank Correlation).

SUMMARY

The tallgrass prairie ecosystem is a highly valued resource in much of the Midwestern portion of North America, but the rate at which highly diverse tallgrass prairie vegetation can be restored on abandoned farm land is slow at best (Kindscher and Tieszen 1998). Major efforts are thus being made to find methods that accelerate the prairie restoration process (for example, Warkins and Howell 1983; Sperry 1994; Packard and Mutel 1997). Because soil nitrogen availability has been demonstrated to have strong effects on the competitive success of native tallgrass prairie species, maximizing the intensity of nitrogen competition should help to favor the establishment and ecological success of these highly desirable species during the restoration process. For example, the use of organic matter supplements to reduce soil nitrogen availability has been used with success during tallgrass prairie restoration by Morgan (1996).

Measurements of soil N should also be considered in the context of soil phosphorus availability. In the study reported here, soil Bray P measurements suggested that phosphorus could potentially be growth-limiting for some of the plant species that were present in our experimental plots. Similarly, in recent tallgrass prairie restoration effort near Lincoln, Nebraska, Stelling and Stock (2000) also reported low soil P concentrations, suggesting that co-limitation of plant communities by both N and P potentially may occur elsewhere in the Midwest as well. In situations of possible N and P colimitation, the data from Fig. 1 and Fig. 2 above suggest that small additions of superphosphate fertilizer may greatly enhance the success of native grasses in replanted tallgrass prairies by increasing soil Bray P, thereby intensifying the degree of N-limitation experienced by the plant community. As noted above, C_4 species such as big bluestem (*Andropogon gerardi* Vitman) and Indian grass (*Sorghastrum nutans (L.)* Nash) are competitively favored by strongly N-limited conditions, and thus artificial amendments of some restored prairie tracts with modest quantities of P may result in accelerated rates of succession towards eventual dominance of highly desirable prairie bunchgrasses. This hypothesis should be tested further in additional tallgrass prairie restorations in which the vegetation potentially experiences N and P co-limitation.

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