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Short-term Intensive Sustainable Restoration of Grasslands and Prairies Invaded with High Densities of Nitrogen-fixing Weeds: A Test with the Invasive Plant Lespedeza Cuneata

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Short-term Intensive Sustainable Restoration of Grasslands and Prairies Invaded with High Densities of Nitrogen-fixing Weeds: A Test with the Invasive Plant *Lespedeza Cuneata*

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Abstract: This study examines a management strategy for restoring grassland and prairie communities that have become degraded due to high density stands of invasive nitrogen-fixing plants. The novel management applications minimize the use of herbicides and maximize the competitive interactions of native species. The management method includes two seasons of application of organic fertilizer (4-1-4), an initial herbicide (Pasture Gard, Dow Agro) application, and mowing, where mowing was a necessary treatment to control secondary growth in prairie habitats, to control high density patches of *Lespedeza (L.) Cuneata*, in a completely randomized factorial experiment. The herbicide was effective in reducing *L. Cuneate* stem density 0 stems/m^2 from an initial 88 stems/m^2 with cover reduced to 0% from 16%. The fertilizer only treatment reduced *L. Cuneata* percent cover to 6% from initial cover of 16%, but did not reduce the number of stems. The management strategy is an effective first step in restoring a native prairie invaded by a nitrogen-fixing plant.

Keywords: Legumes, nitrogen-fixing plants, *Lespedeza Cuneata*, prairie/grassland restoration, invasive species, sustainable management.

1. Introduction

Lespedeza (L.) Cuneata is a long-lived perennial legume that has become a pervasive problem in old fields and prairies throughout parts of the United States [1-6]. For example, areas invaded by *L. cuneate* have lower plant and animal diversity than areas dominated by native grasses and forbs [5, 7]. To promote much higher plant and animal diversity, there is a strong interest in restoring natural ecosystems and therefore, there is a demand for techniques that both control a given invasive species and improve the establishment of native flora and fauna [5, 8-11]. Since the introduction of *L. Cuneata*, it has become a successful invader and colonizes and once it is established, it shades native plants and reduces soil nutrient levels [3, 10, 12]. *L. Cuneata* also has allelopathic effects that reduce seed production and growth of native plants [12]. It is a model invasive nitrogen-fixing plant [1]. Typical tallgrass prairie management and restoration strategies of mowing and burning to remove secondary growth and promote species diversity have facilitated the spread and dominance of *L. Cuneata* [12]. For example, early spring burning and mowing allow for more direct sunlight favored by *L. Cuneata*, while spring burns increase *L. Cuneata* germination rate via seed scarification [3, 10].

L. Cuneata is typically managed by the application of herbicides, typically along roadsides, in animal food plots, and in areas being restored to a native prairie [5, 10]. Studies have indicated herbicide applications increase native plant biomass and reduce *L. Cuneate* cover and stem density [5, 6, 13]. While

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low density stands of *L. Cuneata* have been successfully controlled by spot spraying, fields that have become heavily invaded require repeated applications of herbicide [4], which can be both expensive and not conducive to sustaining a diverse healthy ecosystem. Clearly, an alternative control method for high density stands of a nitrogen fixing weed like *L. Cuneata* needs to be developed.

Fertilization is a relatively novel treatment for nitrogen-fixing plants like *L. Cuneata*, in which the soil is enriched to promote competition of native species [14]. For example, the application of ammonium nitrate to provide nitrogen (N) has been shown to lower the competitive advantage of *L. Cuneata* by significantly reducing cover, stem density, and biomass [2, 12]. Nitrogen applications have also been shown to have a detrimental effect on legume nodule formation and subsequent nitrogen uptake, as well as compensate for the negative effects of the allelopathic chemicals released by the plant [7, 12]. Therefore, adding N to old fields and reclaimed prairies that typically have poor soil fertility may help native species compete with *L. Cuneata* [2, 12, 14, 15]. However, a few experiments where N has been applied, N was applied at very high concentrations [2, 12, 14, 16, 17], which is not cost effective or environmentally sustainable. Current tall grass management strategies, using prescribed fire and fuel management to manage natural resources, have been successful in reducing and maintaininga low abundance of woody growth, but have not been successful in reducing *L. Cuneata* dominance [13, 18, 19]. The goal of this research was to examine whether an applicationof an herbicide and low nitrogen concentration organic fertilizer along with management required mowing regimes to reduce woody plant stems would facilitate the restoration and management of native prairies that have become almost completely dominated by *L. Cuneata*.

Specific questions addressed by this study were: (1) What are the effects of an initial application of a herbicide that is marketed for controlling *L. Cuneata*, PastureGard (Dow AgroSciences), and the application of low nitrogen concentration organic fertilizer, and schedule mowing on *L. Cuneata* stem density, cover, and importance value? (2) How does an initial application of herbicide followed by two years of organic fertilization and mowing affect cover of desired and undesired tallgrass prairie species and species richness after two years?

2. Methods

2.1 Study Site

Wilson's Creek National Battlefield (WCNB), which is located in Southwestern Missouri in the United States of America (37º06'56.04" N, 93º25'12.17" W) is a 708 hectare park that contains 172 hectares of remnant tallgrass prairie and agricultural area [20, 21]. In 1960, the area was made a National Park and has maintained to the physical environment which existed in 1861 during the Civil War battle using periodic burns and removal of secondary growth by mowing [20, 22].

The soil in the restored tallgrass prairies in the WCNB include Wilderness cherty silt loam, Goss cherty silt loam, and a Gasconade-Rock outcrop complex [21]. There are 126 herbaceous and shrub species found within the park; the predominant native tall grass prairie species include big bluestem (*Andropogon gerardii*), and Indian grass (*Sorghastrum nutans*) [21]. The prairies of the park are heavily managed to reduce invasive exotic species, such as *L. Cuneata* (sericea lespedeza) and *Rubus fruticosus* (blackberry), which reduce the cover and presence of native species. This study focused on a 53 ha unit of tallgrass prairie habitat in the northwest part of the park that contained high density stands of *L. Cuneata* (98.2 ± 40.3 stems m^2) that had an average cover of 54.8%, which was managed using fall mowing and spring burns. The Prairie Cluster Long-term Ecological Monitoring Program, carried out by the National Park Service Heartland Inventory and Monitoring Network,

performed a four year study (1997-2000) at WCNB that found the relative cover of exotic species across the park was 30.37%, and the relative cover of native species was 69.88% per 10 m^2 [21].

2.2 Study Design

A fully factorial random block design was used to assess the effectiveness of mowing, herbicide, and fertilization in controlling high density stands of *L. Cuneata* to a manageable density (six blocks, eight treatments, replicated in each block for 48 plots total). An area of 720 m^2 within the 53 ha prairie unit was haphazardly demarcated on a grid map of WCNB. The map was then demarcated into 24-30.0 × 30.0 m blocks; six blocks were then chosen randomly using a random number generator (Minitab 15). Each block was demarcated into 36-5.0 × 5.0 m plots; 8 out of the 36 plots within each block were selected using a random number generator (Minitab 15). A GPS coordinate was recorded for the center of every plot using a Garmin GPS map 76 CSx (position accuracy 1-5 m) along with stacking the corners of each plot.Within a block each of the eight plots received a randomly selected treatment (control, herbicide (H), fertilization (F), mowing (M), M × H, M × F, H × F, M × H × F).

2.3 Treatments

Triclopyr ester and fluroxypyr (PastureGard, 0.02 kg L^{-1} active ingredient) was used as the herbicide to control *L. Cuneata* following manufacturer's instructions. The herbicide was only applied in the first growing season of the study in mid-July on the entire assigned 5 m^2 plot. The fertilizer used was "Perfect Pasture and Farm" developed by Bradford Organics, which is ideal for areas where high inorganic nitrogen fertilization would be prohibited for environmental reasons (e.g., nutrient runoff) and expensive. The ratio of nitrogen, phosphate (P_2O_5), and potash (K_2O) in the organic fertilizer is 4-1-4. This fertilizer is an alfalfa-based organic fertilizer which also contains molasses, sulfate of potash, Humate (Humic acid), and meat meal. There was a total of 26.68 kg of fertilizer (1.067 kg of nitrogen, 0.2668 kg of phosphate, and the 1.067 kg of potash) applied each July and August of the 2-year treatment period on a total area of 600 m^2,or 444.6 kg/ha. Mowing (typical management strategies for tall grass prairies) was applied during the flowering stage of *L. Cuneata* to prevent seed formation. Plots were mowed to a height of 0.1-0.2 m only in the first growing season in early August.

2.4 Measured Variables

The assessment of *L. Cuneata* stem density was determined by counting the number of stems in four randomly chosen 0.25 m^2 areas within each 5 m^2 plot. Daubenmire cover values were used for accessing the species cover for every species that was rooted within each 5 m^2 plots [23]. Every species was then categorized as Native or Nonnative and classified by growth habit (Woody, Herbaceous and Grass), to identify if the species is desired or undesired for a tallgrass prairie. Species richness was accessed by the count of the number of species rooted within each 5 m^2 plot.

The National Park Service's division of Heartland Network Inventory and Monitoring and Prairie Cluster Long-term Ecological Monitoring Program methodology was used to characterize the treatment effects on the *L. Cuneata* population within each treatment level [21]. First there was an assessment of the relative cover of *L. Cuneata* (% cover of *L. Cuneata*/% cover or all other species), and then the relative frequency of *L. Cuneata* (# of occurrences/total species richness) was used to calculate the % Importance Value ([relative cover/relative frequency] × 100).

The data for each variable was collected with three pretreatment measurements taken from April to early May in the first year of the study. Post treatment measurements were taken late May, June and

September of the first year of the study and again with two measurements during the second year in May and June. The post treatment data presented reveals the effects of herbicide (applied only in the first growing season), fertilizer (applied in the first and second growing season) and mowing (applied in the first growing season).

Analysis of variance using a general linear model was used to assess a main treatment effect across all measurements. A Tukey Simultaneous Test utilizing a pairwise comparison among treatments was used to assess statistical differences of individual treatments, which was appropriate because the main treatment effects were statistically significantly different ($P < 0.05$).

3. Results and Discussion

3.1 Treatment Effects on L. Cuneata

L. Cuneata was effectively controlled across all treatments that included Herbicide (H, HxF, HxM, and HxFxM) (Fig. 1 and Table 1). Other studies have demonstrated that the active chemicals triclopyr ester and fluroxypyr ester found in the herbicide PastureGard (Dow AgroSciences) control *L. Cuneata* [5-6, 13] and this study confirms it is effective.

The organic fertilizer only treatment did not significantly increase *L. Cuneata* stem density, but did significantly reduce *L. Cuneata* mean percent cover of 4.2 ± 6.3 (Table 1; Tukey P = 0.3907) (Fig. 1). The fertilizer only treatment reduced *L. Cuneata* importance value to 16.8% compared to 29.4% in the control (Table 1). This is evidence that a slow release organic fertilizer can reduce the dominance of *L. Cuneata* and allow the other native species to compete better without the use of herbicide [2, 15]. Fertilizer combined with mowing only reduced *L. Cuneata* stem density by 1.3% compared to the control; however, it did reduce *L. Cuneata* percent cover to 4.6 ± 1.6 (Fig. 1 and Table 1). The importance value reduction by 48% also reflected that fertilizer combined with mowing was an effective mode of control for *L. Cuneata* (Table 1). The reduction of *L. Cuneata* importance value may be attributed to mowing opening up the canopy, and fertilizer enabling all other species to better compete with the faster growing invasive legume. The mow only treatment did not significantly affect *L. Cuneata* cover with only a 6.1% reduction (Tukey P = 0.9951), but did significantly increase stem density by 28.8% (Tukey P = 0.0007) (Table 1). The highest importance values for *L. Cuneata* were in the control (29.4%) and mow only treatments (29.2%); therefore, mowing alone did not successfully control *L. Cuneata*, which is consistent with the findings of Brandon and Middleton [12].

3.2 Treatment Effects on Other Species

Desired species had the highest percent cover in HxM, HxF and herbicide only treatment with values of 66.2%, 47.4%, and 46.8% respectively. Although not statistically significant, the desired species in the fertilizer only treatment had 11.4% greater percent cover than the control. The desired species percent cover was at or below the control value (24.2%) in the treatments of H × F × M, Mow and F × M. Identifying treatment effects on desired species is important for factor for accessing the success of each restoration plan [5].

To understand the relationship that treatments had on the undesired species, the percent cover of *L. Cuneata* was separated from the remaining undesired species shown in Fig. 1. It is important to create a management strategy to restore native plant communities that reduce L. Cuneata dominance, but that does not result in other undesired species gaining importance, which is known as the invasive treadmill effect [24]. Herbicide only treatment and the H × F × M had the highest percent cover of undesired species with percentages of 61.7% and 56.2% respectively. Similar to Brandon and Middleton [5], our prairie management treatments did not affect the percent cover of undesired species (Fig. 1). Most importantly, herbicide alone increased species cover of undesired

species, but HxF

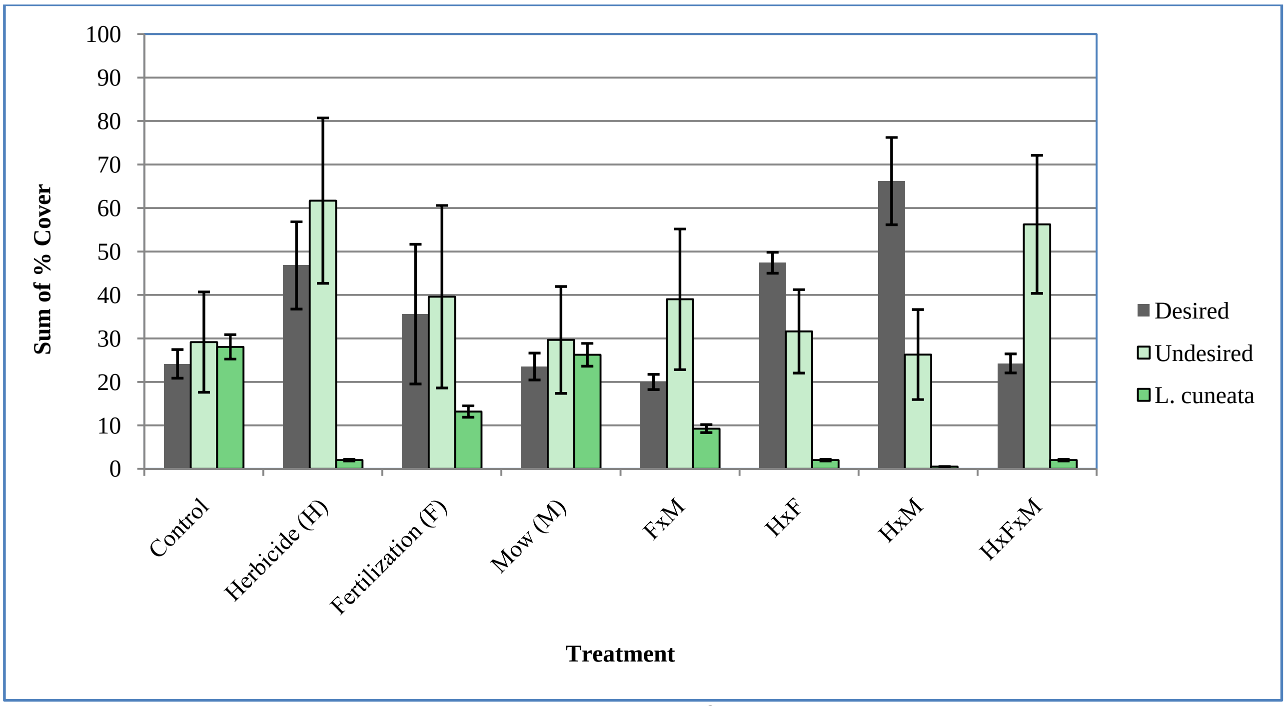

Fig. 1 Summation of all species accessed in percentage per 5 m^2 using the Daubenmire cover value scale in the post treatment period. Species were categorized into Desired (native grasses and native herbaceous plants), Undesired (Native woody, nonnative grasses, nonnative herbaceous, nonnative woody), and *L. Cuneata*.

Table 1 Post treatment data for *L. Cuneata* stem density (number of *L. Cuneata* stems in four 0.25 m^2 sub-plots with in the 5 m^2 plot) and Importance Value Percentage for *L. Cuneata* ([relative cover/relative frequency] × 100).

Treatment	*L. Cuneata* stemdensity (Mean ± SE)	Importance value (%)
Control	87.7 ± 18.1	29.40
Herbicide (H)	0.0 ± 0.0	2.55
Fertilizer (F)	100.0 ± 14.0	16.84
Mow (M)	117.2 ± 16.9	29.19
FxM	85.8 ± 8.6	18.08
HxF	0.1 ± 0.1	1.28
HxM	0.0 ± 0.0	4.25
HxFxM	0.0 ± 0.0	1.57

increased desired species cover. Therefore, the restoration method should facilitate competitive ability of desired species into the future and the efficacy of seeding post treatment [8].

3.3 Species Richness

PastureGard significantly reduced species richness in every plot that it was applied (Table 2). This confirms what Koger, C., et al. [5] reported that PastureGard not only targets *L. Cuneate*, but also inhibits the growth of woody species, herbaceous species, and does not promote an increase in species richness. Although not significant, the fertilizer only treatment had the highest species richness of desired species (Table 2). An increased diversity of species can prevent ecosystem nutrient loss and increase ecosystem productivity [12, 20]. The remaining non-herbicide treatments and treatment combinations also did not have a significant effect on species richness. This may be attributed to only being a short term study, a common problem in invasive plant control experiments [11].

Table 2 Post treatment data for Species Richness (all species rooted within each 5 m^2 plot).

Treatment	Species Richness (Mean ± SE)
Control	8.8 ± 0.5
Herbicide (H)	7.6 ± 0.6
Fertilizer (F)	9.3 ± 0.9
Mow (M)	8.5 ± 0.6
FxM	9.3 ± 0.5
HxF	6.7 ± 0.8
HxM	7.4 ± 0.4
HxFxM	6.9 ± 0.4

4. Conclusion

This study illustrated that the herbicide PastureGard was an effect means to control *L. Cuneate*; however, the herbicide did not significantly reduce other undesired species from filling the ecological niche that *L. Cuneata* left behind. However, by adding the organic nitrogen treatment and standard mowing, initial restoration goals were met. Fire was not allowed in the study, but it can be hypothesized that if fire was added, the restoration goals would have been more completely met. The restoration method will also allow effective seeding of desired species as it opened up niches. The restoration method was more successful than the methods used previously in this prairie and is suggested for the initial treatment of highly invaded grasslands and prairies.

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