EFFECTS OF MECHANICAL AND CHEMICAL CONTROL ON *MICROSTEGIUM VIMINEUM* AND ITS ASSOCIATES IN CENTRAL WEST VIRGINIA

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Abstract—Various studies have identified methods for effectively controlling Japanese stilt grass [*Microstegium vimineum* (Trin.) A. Camus]. However, the effect of *M. vimineum* control treatments on native flora has not been documented. This is of particular interest because an effective *M. vimineum* control method that minimizes impact on native vegetation should be considered the most desirable technique. This study investigates the effects of various control treatments on *M. vimineum*, and the associated native understory community, on an upland and bottomland hardwood site in central WV (38°46' 08"N, 81°03' 52"W). Control treatments examined in the study included: a low-volume glyphosate application (6 ounces per acre); both a single (early June) application and a double application (early June and August) of fenoxaprop-p-ethyl (13 ounces per acre); and mechanical control (weed whip). In the first growing season following the treatments, single applications of fenoxaprop-p-ethyl provided greater than 95 percent control of *M. vimineum* at both sites. Mechanical control also proved to be very effective. In addition to showing an increase in species diversity, fenoxaprop-p-ethyl treated plots also exhibited post-treatment species richness values that were significantly higher than all other treatments ($P < 0.05$). The results of this study suggest that this selective herbicide has the potential to be used to restore native plant communities in *M. vimineum* infested areas of mixed hardwood forests.

INTRODUCTION

Invasions by alien plants are a growing challenge worldwide to the management of native biodiversity and ecosystem functioning (Brooks and others 2004, Gordon 1998, Steele and others 2006). In mixed deciduous hardwood forests of the eastern United States, invasive shrubs, vines, trees, and grasses are threatening native flora, as well as the habitats that they compose. Of particular importance, in WV and throughout the central Appalachians, is the impact of Japanese stilt grass [*Microstegium vimineum* (Trin.) A. Camus] on forest reproduction and economically valuable herbaceous plant communities, e.g., American ginseng (*Panax quinquefolius* L.), goldenseal (*Hydrastis canadensis* L.), and black cohosh [*Cimicifuga racemosa* (L.) Nutt.]. Once established, *M. vimineum* is capable of crowding out native herbaceous vegetation in wetlands and forests within three to five years (Barden 1987, Hunt and Zaremba 1992). Despite not being listed on the United States Department of Agriculture invasive and noxious weeds list for WV, some feel that Japanese stilt grass should be considered as the state's greatest threat to native forest understory habitat (WVDNR 2006).

M. vimineum, also commonly referred to as stilt grass, annual jewgrass, wire grass, Nepalese browntop, and Chinese packing grass, is a shade tolerant C_4 annual grass of Asiatic origin. The exotic grass was introduced into the United States in 1919 in Knoxville, TN (Fairbrothers and Gray 1972). Placed in an environment with no natural enemies, the aggressive grass readily reproduced and began to disseminate. Today, it is widely distributed in dense patches on river banks, flood plains, damp fields, swamps, lawns, woodland thickets, logging roads, and roadsides throughout the eastern United States (Barden 1987, Cole and Weltzin 2005, Fairbrothers and Gray 1972).

M. vimineum possesses several traits that contribute to its competitive and invasive nature. The grass shows a very plastic response to varying habitat conditions (Claridge and Franklin 2002, Gibson and others 2002, Tu 2000, Winter and others 1992). For example, *M. vimineuem*, like all C_4 plants, prefers moderate to high light levels for reproduction, dispersal, and establishment, however, *M. vimineum* can grow, reproduce, and disperse seed in only five percent full sunlight (Winter and others 1992). *M. vimineum* has also been reported to promote positive feedback processes with the soil, further enhancing its ability to spread (Gibson and others 2002, Kourtev and others 1998, Tu 2000). The exotic invasive grass also possesses a persistent seed bank that remains viable for three to seven years (Barden 1987, Gibson and others 2002, Tu 2000). *M. vimineum* is slow to invade undisturbed areas; however disturbance (natural or anthropogenic) favors the establishment of the species (Barden 1987, Oswalt and others 2007, Tu 2000). In West Virginia, *M. vimineum* populations are especially abundant on logging roads and forest edges following operations that disturb the soil and/or forest canopy.

Various studies have identified methods for effectively controlling *M. vimineum*. It should be noted that early control of source populations at forest edges is likely a more effective strategy than concentrating on patches within a forest interior (Cole and Weltzin 2004, Cole and Weltzin 2005, Huebner 2006). The preferred control method is removal of the plant by hand pulling late in the growing season before seed production and after seed set of most co-associates (Gibson and others 2002, Tu 2000). This method provides minimal environmental impact, but is very labor and time intensive, especially when dealing with large populations. Mechanical removal, using a "weed whacker," or "weed eater," also works

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well late in the growing season (Gibson and others 2002, Tu 2000), and is much less labor and time intensive.

Post-emergence herbicides have also been proven effective, and may be the only choice for large infestations. Based on research at the University of Tennessee, the Nature Conservancy recommends using imazapic, fluazipop-P, and glyphosate (Tu 2000). In addition, other research supports the effectiveness of clethodim, fenoxaprop-P, sethoxydim, and glufosinate, (Gover and others 2003, Judge and others 2005a). A preliminary study by Judge and others (2005a) found that double applications of clethodim, fenoxaprop-P, sethoxydim, and glufosinate controlled >90 percent of containerized *M. vimineum* in VA and NC. A single application of glyphosate also provided adequate control. A follow up study by Judge and others (2005b) found that single applications of fenoxaprop-P, imazapic, and sethoxydim controlled *M. vimineum* 83 to 89 percent in both a mixed pine-hardwood and hardwood forest. Seedling emergence in the second growing season following the treatment was reduced 78 to 89 percent (Judge and others 2005b). This study also showed that double applications (four weeks apart), at half the registered rate, were effective (Judge and others 2005b). Herbicide research, however, is limited to these few studies, and is nonexistent in WV. More importantly, the effect of *M. vimineum* control treatments on native understory communities has not been documented. This is of particular interest because an effective *M. vimineum* control method that minimizes impact on native vegetation should be considered the most desirable technique.

This article focuses on the effects of various control treatments on Japanese stilt grass, and the associated native understory community, on an upland hardwood and bottomland hardwood site in central WV. Treatments examined include: a low-volume glyphosate (tradename Accord) application (6 ounces per acre); both a single (early June) application and a double application (early June and August) of fenoxaprop-p-ethyl (tradename Acclaim Extra) (13 ounces per acre); and mechanical control (weed whip). Treatment effects are described for the first growing season following the treatments. Two research questions will be answered, including: (1) what is the efficacy of each treatment for controlling *M. vimineum*? and (2) how does each treatment effect species richness and diversity of the associated understory stratum? The information presented should help foresters and other land managers to better understand how *M. vimineum* control treatments might affect understory species composition and dynamics in the Central Hardwood Region.

METHODS

Study Site

The experiment was conducted in 2006 in established stands of *M. vimineum* on both upland and bottomland hardwood sites. Both sites are located in eastern Calhoun County, WV (38°46' 08"N, 81°03' 52"W), within the Right Fork of Crummies Creek watershed. The area is characterized by average annual precipitation of 42 inches, an average annual temperature of 53.6 ºF, and a growing season of approximately 159 days (Pate 1999). Braun (1950) characterized the area as being part of the mixed mesophytic cover type.

The upland site was selected to focus on treatment effects on the native understory community. This site is located on a skid road on an east-facing slope at an elevation of 1,065 feet. The area was impacted by an ice storm in 1994, and a salvage operation occurred the following year. *M. vimineum* quickly established following the disturbance, and currently encompasses, on average, 58.93 percent of the understory cover along the corridor.

The overstory of the hardwood forest at this site is composed primarily of typical cove hardwood species, including; sugar maple (*Acer saccharum* Marsh.), yellow-poplar (*Liriodendron tulipifera* L.), basswood (*Tilia americana* L.), and hickories (*Carya spp*.). The soil type is of the Gilpin-Peabody complex. These soils are very steep, well drained silt loams. Erosion has removed most of the original surface layer of these soils, and in places the subsoil is exposed (Pate 1999).

The bottomland site was selected to focus on treatment effects on *M. vimineum*. The area is located at an elevation of 821 feet in a valley bottom. The site is located within the floodplain of the Right Fork of Crummies Creek, a small perennial stream. *M. vimineum* has been established in this area since the mid 1990s as well. Here, *M. vimineum* composes, on average, 70.68 percent of the understory cover.

Canopy cover is minimal at the bottomland site and yellow-poplar, slippery elm (*Ulmus rubra* Muhl.), American sycamore (*Platanus occidentalis* L.), and black walnut (*Juglans nigra* L.) are the main species mix. The soil type is known as Sensabaugh silt loam. This soil is nearly level, very deep, well drained, and is subject to occasional flooding (Pate 1999).

Field Methods

Fifteen treatment plots were established at each site. At the upland site, 0.001-acre circular plots, having 3.72 feet radius, were established along the skid road. Plots were placed no closer that 15 feet apart, and percent cover, by species, was visually estimated. Rectangular plots, measuring 23 by 5 feet, were established at the bottomland site. Here plots were inventoried using the point-intercept method (Caratti 2006). Measurements were made at systematic 2-foot intervals, for a total of 20 measurement points per plot. "Hits" were tallied into one of four categories, including; Japanese stilt grass, other grass species, herbaceous species, and woody species. Both sites were inventoried prior to treatment (June), and again in early August and October 2006.

Four treatments were examined, including; a low-volume glyphosate (tradename Accord) application, both a single application and a double application of fenoxaprop-p-ethyl (tradename Acclaim Extra), and mechanical control (weed whip). The glyphosate, a non-selective post-emergence herbicide, was applied at a rate of 6 ounces per acre. This rate is commonly used by Christmas tree growers to stunt grasses to make it easier for customers to walk down rows between trees. Fenoxaprop-p-ethyl, on the other hand, is a selective post-emergence herbicide designed only to kill monocots. Both the single and double applications of this herbicide were applied at the registered rate (13 ounces per acre).

All treatments, and a control (or check), were randomly assigned to plots at both sites (three replicates). Chemical treatments were applied on June 6. The second fenoxaprop-p-ethyl applications, and the mechanical treatment, were applied on August 11 and 15, respectively. Herbicides were applied using a CO_2-pressurized backpack sprayer equipped with a 5 foot boom and 4 fan nozzles. The sprayer was calibrated to deliver 27.76 gallons per acre.

Analytical Methods

Pre and post-treatment percent cover data were arcsine transformed for both sites, and *M. vimineum* control was quantified by the percentage change in these values. Percentage change was calculated by subtracting pretreatment values from post-treatment values, dividing by pretreatment values, and multiplying the quotient by 100. Upland site species richness, or the count of a number of different species, was also evaluated for both pre and post-treatment data. Species diversity was quantified, for the upland site, for both pre and post-treatment data using Simpson's Diversity Index (SDI) (Simpson 1949). With SDI, species diversity can range from zero to one with values closer to zero representing higher diversity. This is sometimes a bit confusing, so all SDI values were subtracted from one. This made the results less puzzling by making higher SDI values represent higher diversity.

All statistical analyses were performed using SAS 9.1 software (SAS Institute, 2003), with significance determined at $\alpha \leq 0.05$. Treatment effects on percentage change in *M. vimineum* cover, species richness, and species diversity were assessed using a General Linear Model (GLM) procedure. Mean comparisons were evaluated using Fisher's protected Least Significant Difference (LSD) test (t-test). The null hypothesis of the study (H_0) was that there was no difference in dependent variables across treatments.

RESULTS AND DISCUSSION

***M. vimineum* Control**

Both single (Acclaim 1) and double applications (Acclaim 2) of fenoxaprop-p-ethyl, as well as the weed whip treatment, provided, on average, greater than 97 percent control of *M. vimineum* at the upland site (fig. 1). These three treatments were significantly different from both the glyphosate treatment and the untreated plots. These findings were comparable to those of the experiments conducted by Judge and others (2005a) and Judge and others (2005b). Glyphosate provided, on average, only a 23 percent reduction in *M. vimineum* cover. On untreated plots, *M. vimineum* cover increased by an average of 44 percent.

Results at the bottomland site were somewhat similar. Once again, both a single application of fenoxaprop-p-ethyl and the weed whip treatment provided adequate control of *M. vimineum*. These two treatments were significantly different from both glyphosate treated plots and untreated plots. They were, however, not significantly different from the double application of fenoxaprop-p-ethyl, which only provided, on average, a 54 percent reduction at this site (fig. 2). The glyphosate treatment caused only a minute decrease (2 percent on average) in *M. vimineum* cover, and again, *M. vimineum* cover increased quite dramatically on untreated plots.

The ineffectiveness of the glyphosate treatments, at both the bottomland and upland sites, disagrees with other published

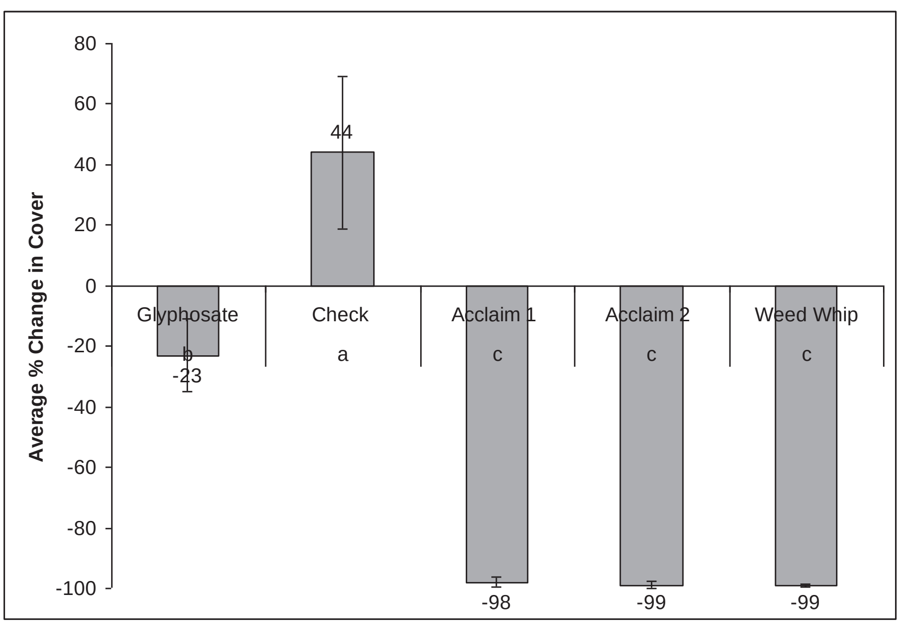

Figure 1—Average percent change in *M. vimineum* cover by treatment: upland site. Means with the same letter are not significantly different at $\alpha \leq 0.05$. Error bars represent +/- one standard error.

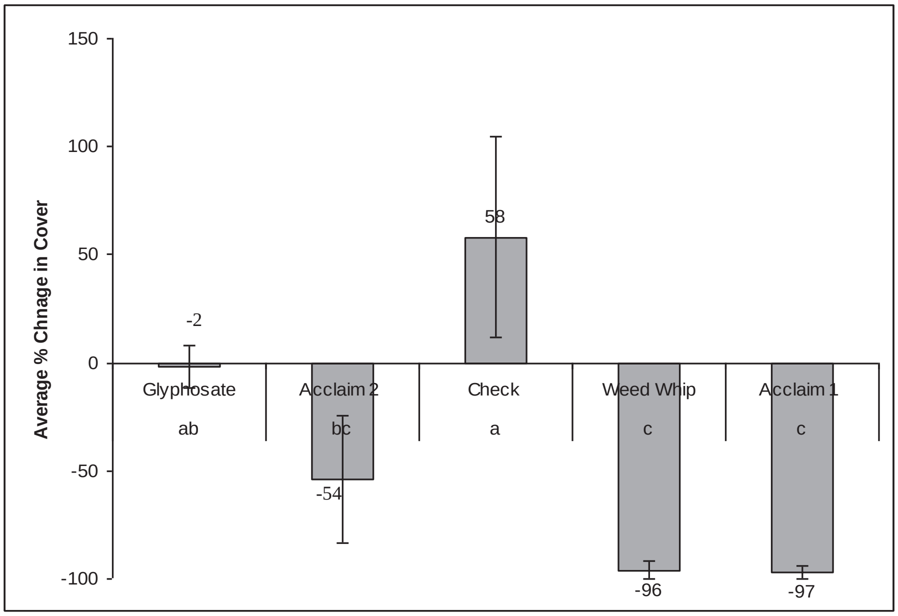

Figure 2—Average percent change in *M. vimineum* cover by treatment: bottomland site. Means with the same letter are not significantly different at α≤0.05. Error bars represent +/- one standard error.

studies. It should be noted, however, that, in this study, glyphosate was applied at about 1/5 the rate of other studies. Also, two of the glyphosate treated plots at the upland site were not completely covered when sprayed. That is, 1/2 of those plots were missed by the sprayer. This fact certainly caused some bias in the results and glyphosate, therefore, can not be ruled out as having the potential to be an effective management tool.

Species Richness

In June, species richness ranged, on average, from 12 to 16 at the upland site. At this time, the values were not significantly different between treatment plots. In August, species richness values were still quite similar, and ranged from 11 to 16. Again, these values were not significantly different at α≤0.05. By October, however, a noteworthy difference was observed (fig. 3).

Here, species richness ranged from 8 to 17, and plots that were treated with both single and double applications of fenoxaprop-p-ethyl showed average species richness values that were significantly higher than the glyphosate, weed whip, and untreated plots. Much like the findings of Oswalt and others (2007), where *M. vimineum* cover increased (untreated plots) species richness decreased (16 species in June to eight species in October). Plots that were treated with both single and double applications of fenoxaprop-p-ethyl contained 17 and 15 different species, respectively.

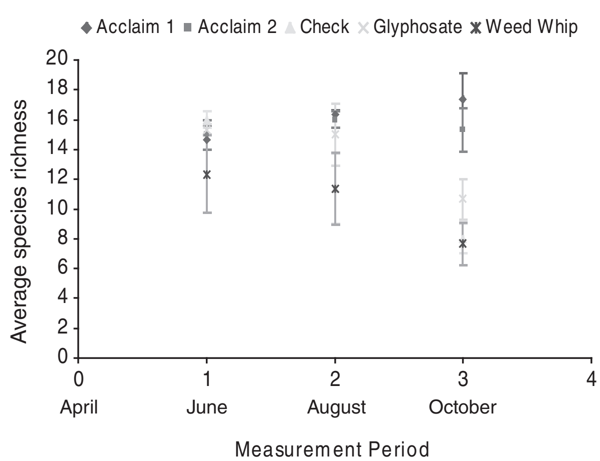

Figure 3—Average species richness by treatment and measurement period. Error bars represent +/- one standard error.

Table 1—Most frequently encountered species: upland site

Rank[a]	Common name	Scientific name
1	Sugar maple	*Acer saccharum* Marsh.
2	Fall fescue	*Festuca spp.*
3	White snake root	*Eupatorium rugosum* Houtt.
4	Jack-in-the-pulpit	*Arisaema triphyllum* (L.) Schott
5	False nettle	*Boehmeria cylindrica* (L.) Sw.
6	White grass	*Leersia virginica* Willd.
7	Large yellow wood sorrel	*Oxalis europaea*
8	Aborted buttercup	*Ranunculus aborvitus*
9	Hairy bittercress	*Cardamine hirsuta* L.
10	Spicebush	*Lindera benzoin* (L.) Blume

[a]Rank is based on frequency of occurrence in study plots.

Table 1 lists the ten most frequently encountered species at the upland site (post-treatment). These are, however, only a fraction of what was actually encountered. In addition to these species, we came across an astounding 77 other herbaceous, grass, and woody species; indicating a high potential for restoration of native plant communities in *M. vimineum* infested areas.

Species Diversity

Figure 4 shows average species diversity before and after treatments. Treatments are arranged from smallest change to largest change, reading left to right. Plots that received both single and double applications of fenoxaprop-p-ethyl, as well as the weed whip treatment, experienced an increase in species diversity from pretreatment to post-treatment (fig. 4). The change in species diversity for these three treatments was significantly different from untreated plots at $\alpha \leq 0.05$.

Both the single application fenoxaprop-p-ethyl and weed whip treatments were also significantly different from the plots treated with glyphosate. Both glyphosate treated, and untreated, plots resulted in decreased species diversity. The weed whip results, however, may be a bit misleading because species diversity is relative to the amount of cover. Post-treatment percent cover on weed whip plots averaged only 10.3 percent, compared to 46 and 47.3 percent on the single and double application fenoxaprop-p-ethyl plots. Examination of mechanical treatments over multiple growing seasons would limit bias and likely produce more indicative results.

Compositional Trends: Bottomland Site

Despite the lack of species richness and diversity data, a few compositional trends could still be noted at the bottomland site. In general, as *M. vimineum* cover increased, native understory

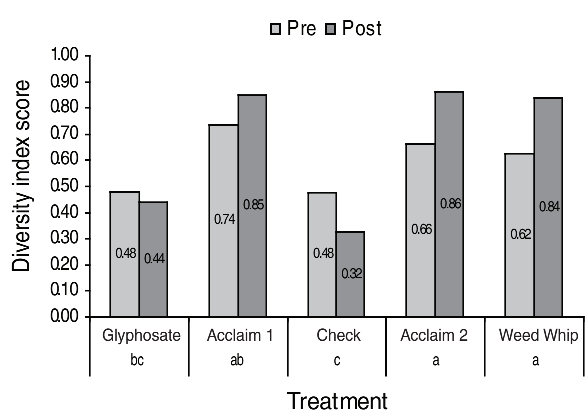

Figure 4—Pre-treatment vs. Post-treatment Diversity Indices. Treatments with the same letter are not significantly different at $\alpha \leq 0.05$.

Table 2—Average percent change in cover (pre- to post-treatment) by species group and treatment: bottomland site

Species Group	------------ Treatment ------------				
	Acclaim 1	Acclaim 2	Check	Glyphosate	Weed Whip
M. vimineum	-97 c	-54 bc	58 a	-2 ab	-96 c
Herbaceous	17 a	0 ab	-58 c	-30 bc	-15 ab
Other Grass Spp.	21 a	4 ab	-22 ab	-39 b	-22 ab

For each species group, means with the same letter are not significantly different at $\alpha \leq 0.05$.

flora decreased and vice versa. Herbaceous and other grass species percent cover increased on plots treated with a single application of Acclaim (table 2). Native flora experienced only a minute change on plots treated with two Acclaim applications. Native herbaceous and grass species decreased on untreated, as well as, glyphosate and weed whip treated plots. It should be noted that woody species were not included in the analysis because so few were present on the plots.

CONCLUSIONS

Our results indicate that if *M. vimineum* is left untreated, it will readily out-compete native understory vegetation and begin to dominate a site. These finding are consistent with those of Barden (1987) and Oswalt and others (2007).

The results also point out a single application of Acclaim Extra, or fenoxaprop-p-ethyl, as being the best choice for controlling *M. vimineum* populations, and maintaining native understory flora in mixed hardwood stands of West Virginia. A double application of the chemical is unnecessary and will only cost the land manager more time and money. Mechanical control also proved to be very effective; again, however, the effects of this treatment on native vegetation need to be examined for more than a single growing season.

However, more research is needed on this topic for it to be fully understood. The effects of different selective herbicides on native vegetation should be examined. This study only compared selective and non-selective. Again, effects should be monitored over multiple growing seasons as well. A cost evaluation, for controlling both small and large infestations would also be very useful, especially for private landowners. Finally, it needs to be determined if biological control is a possibility. Pathogens, insects, and viruses have been proven to be effective for controlling other exotic organisms, and could be the missing link to widespread control of the aggressive, non-native, grass *M. vimineum*.

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