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Mowing Any Time after Midsummer Can Manage Japanese Stiltgrass

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Japanese stiltgrass is one of the most aggressive, rapidly spreading invasive plants in the eastern United States. Management guidelines state that mowing can help manage Japanese stiltgrass but that mowing is most effective when done late in the season after the plants begin to flower and before they set seed. In this study, I tested the effectiveness of mowing at three different times between mid-June and early September in 2009 and 2010, as well as mowing twice in 1 yr and for two consecutive years. The effectiveness of mowing Japanese stiltgrass was determined by measuring percentage of cover, biomass, seed production, and the number of stems in the summer following mowing. All mowing treatments significantly reduced percentage of cover, biomass, seed production, and the number of Japanese stiltgrass stems the following year. In 2009, all of the mowing treatments significantly reduced biomass, percentage of cover, and seed production. The latest mow, at the end of August, resulted in a slightly greater reduction of cleistogamous seeds. In 2010, the earliest mowing treatment, in mid-June, did not reduce cover and biomass as much as the other mowing treatments. Overall, these results suggest that mowing can be an effective control method for Japanese stiltgrass and that mowing any time after June should be effectively equivalent, although later mowing may provide some marginal advantage.

Nomenclature: Japanese stiltgrass, *Microstegium vimineum* (Trin.) A. Camus var. *imberbe* (Nees) Honda.

Key words: Mowing, mechanical control, invasive plant, management.

Japanese stiltgrass [*Microstegium vimineum* (Trin.) A. Camus] is an invasive annual grass that is spreading rapidly through eastern U.S. forests. It was first reported from Knoxville, TN, in 1919 (Fairbrothers and Gray 1972), and was first noted as invasive in 1987 (Barden 1987). Since the late 1990s, it has spread rapidly from the southern states of Tennessee and North Carolina to cover many areas of the eastern United States, reaching as far north as New York (Hunt and Zaremba 1992; USDA NRCS 2009). When it invades a site, it can quickly become very abundant and displace native understory vegetation, reduce native plant diversity and biomass, and inhibit tree regeneration and forest succession (Adams and Engelhardt 2009; Flory and Clay 2010; Oswalt et al. 2007).

The accepted control methods for Japanese stiltgrass include grass-specific herbicides, hand-pulling, and mowing (Flory 2010; Judge 2005; Tu 2000). It is generally accepted that mowing is most effective when done late in the season after plants begin to flower, but before they set seed. Mowing earlier in the season is considered less effective because plants can regrow and still produce seeds (Derr 2004; Gover et al. 2003; Richardson 2011; Swearingen 2009). However, none of these studies have rigorously tested the effect of mowing at different times in the season. The recommended time window for mowing Japanese stiltgrass is short, less than 1 mo, between the initiation of flowering and time of seed maturation. This leaves little time for managers to mow affected areas, and if mowing is done after seeds mature, it could result in increased seed spread.

Derr (2004) states ''some plants mowed approximately one month before bloom were able to produce seedheads, although seedhead numbers were significantly reduced compared to unmowed controls. Later mowings were more effective,'' but no data on the difference in efficacy are presented to support this claim, and no data are presented for seed production in the different treatments. Gover et al. (2003) compared multiple pre- and postemergent herbicides as well as late-season mowing with a string trimmer. Their data show that mowing was as effective as most of the postemergent herbicides tested. They present no data on early-season mowing, yet state in the conclusions that ''stiltgrass tolerates mowing initiated early in the season,'' without supporting data or clear explanation of what time is considered ''early.'' Flory and Lewis (2009) compared different control methods for Japanese stiltgrass and found that late-season mowing reduced Japanese stiltgrass cover by 70% and biomass by 95% compared to untreated plots,

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Management Implications

Mowing is used to control many invasive plant species. For some species, such as Japanese stiltgrass, the timing of mowing within the season is considered important for effective control. The accepted mowing method for Japanese stiltgrass is to mow late in the summer after the plants begin to flower. Mowing earlier in the summer is believed to allow plants to recover and set seed, and is generally considered an ineffective control strategy. However, the evidence to support the importance of late-season mowing is limited and has not been rigorously tested. I tested three timings of mowing (from June to September), and the effect of mowing twice in a year, on Japanese stiltgrass invasions. The earliest mowing treatment (June 18) was less effective than the other timings, but all other times after July 1 significantly reduced cover, biomass, seed production, and the next year's recruitment of Japanese stiltgrass. Some seed production occurred in all mowing treatments, even plots that were mowed after plants began to flower in September. Much of this seed production was from obligately selfing (cleistogamous) flowers that are produced in the axillary nodes of the grass. These flowers are not apparent without close observation and can be produced even under poor growing conditions. The results of this study suggest that Japanese stiltgrass can be controlled reasonably well by mowing in July or later, and that mowing does not have to be restricted to late summer once plants have begun to flower. Some seed production is still likely, however, and mowing needs to be repeated over several years to reduce the seed bank.

but they did not test the efficacy of mowing earlier in the season.

Because it is an annual species, Japanese stiltgrass must establish from seed each year. Therefore, eliminating seed production and preventing spread of seed to new sites should be the primary management goals. Seeds can remain viable in the soil for up to 7 yr, but germination rates drop off precipitously after 3 yr and most seeds germinate within this time (Barden 1987). Consistent yearly management is essential to reduce the population size of Japanese stiltgrass and limit its ecological effects on native communities. Therefore, control methods need to be both cost- and time-efficient. Although hand-weeding can be an effective strategy, it is rarely cost-effective for large areas. Similarly, grass-specific herbicides can be highly effective at controlling Japanese stiltgrass and have minimal nontarget effects because there are few native grasses with the same late summer growth season as Japanese stiltgrass, but the cost for treating large areas may be unacceptable and their use may be prohibited at some sites.

The goal of this study was to investigate the effect of mowing Japanese stiltgrass at different times in its growth season on percentage of cover, height, biomass, seed production, and the number of stems that recruit the following year. Mowing can reduce seed production of Japanese stiltgrass, but it is unclear how critical the timing of mowing is for effective control. Land managers may not have the time or resources to mow all invaded areas during the recommended late summer time window, and as a result may leave many areas invaded by Japanese stiltgrass untreated. If mowing earlier in the season can provide significant control of Japanese stiltgrass seed production, then it can provide an easier method for land managers to control its spread, even if plants still produce some seeds.

Materials and Methods

Study Site. This study was conducted along an unpaved access road in a parcel of Morgan Monroe State Forest in Monroe County, Indiana (39°11′44″N, 86°25′0″W). Portions of this site had been selectively harvested for lumber in 2003 and 2007. The road is used primarily for property management and timber harvests and does not have public access. Although the invasion is much more extensive in disturbed areas, it has also spread into undisturbed parts of the forest. A map of the property and location of Japanese stiltgrass invasions can be found in a previous publication (Shelton 2011).

Treatments. In June 2009, I established 40 2 by 4–m (6.5 by 13–ft) plots and 10 4 by 4–m control plots in 10 blocks along the roadside. All plots were intentionally chosen to have a high density of Japanese stiltgrass ($>$ 50% cover). In Indiana, Japanese stiltgrass germinates in late April or early May, and typically does not overgrow most native vegetation until July or August. It typically flowers in early September and begins to set seed in late September or early October. Prior to mid-June, Japanese stiltgrass is below the mowing height of most mowers and mowing could disturb the soil and allow more seeds to germinate. Therefore, mowing before mid-June is likely to be ineffective, and I did not test efficacy of mowing prior to that time.

I tested four treatments that differed in the timing and frequency of mowing and randomly assigned one plot in each block to each treatment. The following treatments were used: early mowing (EARLY), which was after the seedling stage but before Japanese stiltgrass overgrew native vegetation; midsummer mowing (MIDDLE), which was done after Japanese stiltgrass plants had dominated native vegetation but before they began to flower; late summer mowing (LATE), which was done after Japanese stiltgrass plants began to flower but before they set seed; and twice-mowed (TWICE), in which plots were mowed in both early and late summer (Table 1).

The experiment was repeated in 2010 across half of each plot (2 by 2 m) with the same mowing treatment that was used for the plot in 2009. Thus, the mowing treatments in 2010 were applied to plots that had also been mowed in 2009. Due to differences in seasonal phenology, actual mowing dates were different in 2010 (Table 1), but mowing was done when plants were at the same phenological state in both years. The plots were mowed

Table 1. Summary of dates of mowing treatments and data collected.

Date	Mowing treatment	Data collected
July 1, 2009	EARLY and TWICE	% Cover, height
August 12, 2009	MIDDLE	Height
August 30, 2009	LATE and TWICE	% Cover
October 12, 2009	—	% Cover, height, biomass, seed production
June 1, 2010	—	% Cover, height, no. of stems
June 18, 2010	EARLY and TWICE	—
July 28, 2010	MIDDLE	% Cover, height
August 24, 2010	TWICE	% Cover, height
September 8, 2010	LATE	% Cover, height
September 22, 2010	—	Biomass
June 17, 2011	—	% Cover, height, no. of stems

with an Ariens gas-powered push mower (model 911015 [LM 21], 2 cycle sachs 142 cc engine) set to the lowest height setting. This resulted in a cutting height of 0 to 10 cm (0 to 4 in) due to the uneven ground surface. Mowed vegetation was mulched by the mower and left in the plots. This mulch decayed quickly and was generally not apparent by the next mowing.

Data Collection. Before each mowing, percentage of cover and height of Japanese stiltgrass were recorded for each subplot. Percentage of cover was determined by visual estimation across the entire plot, and was always done by the same experienced investigator to minimize estimation bias. After Japanese stiltgrass set seed, all aboveground biomass was harvested from either three (2009) or two (2010) 25 by 25–cm quadrats in each plot. Plants were harvested in early fall of both 2009 and 2010, after plants began to set seeds (see Table 1 for dates). The plants were then sorted in the laboratory to Japanese stiltgrass, other vegetation, and litter. These samples were dried in a 50 C (122 F) oven (Model DX-68 drying oven, American Scientific Products, Charlotte, NC) for 3 d and then weighed (Ohaus Adventurer Pro Balance, Ohaus Corporation, Pine Brook, NJ) to the nearest 0.01 g to record biomass in each treatment.

The number of Japanese stiltgrass stems in each plot was counted the following June in three (2010) or two (2011) randomly located 25 by 25–cm quadrats per plot. These quadrats were located in areas that had not been harvested the previous year. Stem counts were done after initial density-dependent mortality of seedlings. Because Japanese stiltgrass plants produce multiple branched tillers that can reroot, the number of stems is a better estimate of density than the number of plants.

Measurement of Seed Production. In 2009, seeds were collected from the harvested biomass and the top 1 cm of soil within the 25 by 25–cm quadrats. Japanese stiltgrass produces two types of seed: outcrossed chasmogamous (CH) seeds in spikelets at the tip of culms and obligately selfing cleistogamous (CL) seeds in spikelets along the stem of the plant within the leaf sheaths (Cheplick 2006). CH seeds readily fall from the plant as soon as they mature, but many CL seeds remain within the stems after the plant senesces.

In order to capture both types of seed and fully estimate seed production, I collected seeds from three sources. I collected loose seeds that fell from plants in the field or in the laboratory during sorting (CH seed). I assumed the majority of these seeds were from CH flowers because they readily fall from plants, but some percentage of these seeds likely came from CL flowers. Second, I used a 20% sample by weight of the harvested Japanese stiltgrass and dissected out all CL seeds from the leaf sheaths. I multiplied this number of seeds by five to estimate total CL seed production (CL seed) for each quadrat. Finally, I extracted seeds from the soil collected from each quadrat (soil seed). Because seeds were falling from CH flowers at the time of harvest, it is not possible to determine what proportion of the seeds from the soil was from current year seed production vs. from the soil seed bank. Very few seeds ($< 1\%$) of species other than Japanese stiltgrass were found in any of the seed sources.

Seeds were extracted from the soil samples using a technique modified from Malone (1967). For each soil sample, I used 10 g (0.35 oz) sodium hexametaphosphate, 5 g sodium bicarbonate, and 25 g magnesium sulfate dissolved in 200 ml (6.8 fluid oz) of water. The soil sample was added to this solution, stirred for 5 min, and then allowed to settle. Viable seeds and other organic matter that floated to the top of the solution were skimmed off, placed on filter paper and dried in a 50 C oven for several hours. Once dry, I manually searched the organic material for seeds and counted all Japanese stiltgrass seeds. I also sorted the remaining soil that was left behind after extracting seeds by flotation for a subset of samples to determine the efficacy of this method, and found it extracted $93 \pm 2\%$ of all seeds in the soil samples.

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Table 2. Percentage-of-cover and height data over the course of the growing season for plots mowed in 2009.

	Cover				Height			
Mowing treatment	July 1, 2009	August 30, 2009	October 12, 2009	June 1, 2010	July 1, 2009	August 12, 2009	October 12, 2009	June 1, 2010
	%				cm			
Unmowed	84.0 ± 3.2	65.0 ± 4.4	90.5 ± 2.0	87.5 ± 3.1	36.0 ± 2.1	49.5 ± 3.6	74.0 ± 4.5	22.5 ± 1.5
EARLY	79.5 ± 2.7	24.0 ± 2.3[a,b]	7.8 ± 1.7[a,b]	38.0 ± 7.7[b]	32.5 ± 0.9	15.5 ± 2.0[a,b]	32.8 ± 2.2[a,b]	16.5 ± 1.5
MIDDLE	87.0 ± 1.7	12.0 ± 0.8[a,b]	4.4 ± 2.0[a,b]	32.0 ± 7.5[b]	38.0 ± 1.6	48.0 ± 3.9	12.5 ± 1.5[a,b]	18.0 ± 1.9
LATE	87.0 ± 1.7	61.0 ± 3.5	0.7 ± 0.3[a,b]	35.0 ± 8.8[b]	38.0 ± 1.6	46.5 ± 3.9	21.1 ± 3.5[a,b]	19.0 ± 1.5
TWICE	79.5 ± 2.7	11.5 ± 0.7[a,b]	9.1 ± 2.9[a,b]	35.0 ± 7.6[b]	32.5 ± 0.9	15.0 ± 2.1[a,b]	16.7 ± 3.2[a,b]	15.0 ± 1.1[b]

[a] Treatments that had been mowed prior to the time these data were collected.

[b] Values were statistically significant from the unmowed controls for the same date with $P < 0.05$ in Tukey's honestly significant difference test.

Statistical Analyses. All statistical tests were done on mean values for each subplot using PROC MIXED in SAS version 9.2 for Windows (SAS Institute Inc., Cary, NC,). I included block as a random factor and mowing treatment as a fixed factor. Block did not have a significant effect in any of the tests, so the analyses were rerun using PROC GLM with Tukey's contrasts to compare differences among specific treatments.

Results and Discussion

Effect of Mowing on Percentage of Cover and Height of Japanese Stiltgrass. In both years of the experiment, plots that had already been mowed that year had significantly less percentage of cover and shorter mean plant height than treatments that had not yet been mowed (Tables 2 and 3). The timing of mowing had no significant effect on percentage of cover or height of Japanese stiltgrass by the time of the harvests at the end of the growing season. There was also a difference in percentage of cover between mowed and unmowed plots in early June of the year following mowing, but no difference among the different mowing treatments (Table 2 and 3). However, additional sampling of the plots mowed in 2009 showed that the difference between mowed and unmowed plots disappeared by July 2010.

By the end of the growing season in 2009, percentage of cover of Japanese stiltgrass in the mowed treatments was reduced by 90 to 99% compared to the initial percentage of cover measures in June. However, there was no longer any difference in percentage of cover between the mowed treatments and the control by late July of the year following mowing. This suggests the existing Japanese stiltgrass plants may have grown larger with reduced plant density, which conforms to other studies that have shown that the growth of Japanese stiltgrass is density-dependent (Brewer 2011). Similar results were found for the 2010 mowing treatments, which were done on plots that had been previously mowed in 2009, but the magnitude of reduction in percentage of cover was less, ranging from 58 to 79% (Tables 2 and 3). In June of the year after mowing, all of the mowed treatments except the EARLY mow from 2010 had reduced percentage of cover compared to the unmowed controls. However, additional sampling of the 2009 mowed plots later in 2010 showed that the cover of Japanese stiltgrass had increased and was no longer different from the unmowed controls. Thus, it appears that the effects of mowing on percentage of cover of Japanese stiltgrass are transient and likely do not persist beyond early in the year after mowing. This indicates that repeated mowing over multiple years will be required to control Japanese stiltgrass.

Effects of Mowing Treatments on Japanese Stiltgrass Biomass. Mowing significantly reduced the biomass of Japanese stiltgrass compared to unmowed plots. For plots mowed in 2009, all of the mowing times tested had statistically equivalent biomass at the end of the growing season, and all had significantly less biomass than the unmowed control (Figure 1A; $F_{4,144} = 66.25$, $P < 0.0001$). For the plots mowed in 2010, all of the mowing timings, except for the EARLY mowing treatment, had significantly less biomass of Japanese stiltgrass than the control (Figure 1B, $F_{5,172} = 18.55$, $P < 0.0001$). The EARLY mow in 2010 was conducted approximately 2 wk earlier than the EARLY mow in 2009, and this may account for the reduced effectiveness of the EARLY treatment in 2010. Overall, biomass of Japanese stiltgrass at the end of the growing season was slightly higher for the 2010 mowing treatments than for the 2009 mowing treatments (Figure 1). Biomass was reduced by 97 to 99% across all of the mowing treatments in 2009, but was reduced by 58 to 96% in plots mowed in 2010. In both years, the latest mowing timing reduced Japanese stiltgrass

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Table 3. Percentage-of-cover and height data over the course of the growing season for plots mowed in 2010.

Mowing treatment	Cover					Height				
	June 1, 2010	July 28, 2010	August 24, 2010	September 8, 2010	June 17, 2011	June 1, 2010	July 28, 2010	August 24, 2010	September 8, 2010	June 17, 2011
	%					cm				
Unmowed	35.0 ± 3.8	75.8 ± 3.3	81.4 ± 2.6	74.4 ± 3.9	52.1 ± 5.2	17.1 ± 0.8	49.8 ± 2.4	56.6 ± 2.9	54.3 ± 2.7	19.1 ± 1.0
EARLY	38.0 ± 7.7	38.5 ± 9.5^{a,b}	47.0 ± 8.8^{a,b}	31.6 ± 9.9^{a,b}	48.0 ± 10.0^{a}	16.5 ± 1.5	19.5 ± 1.9^{a,b}	25.0 ± 2.9^{a,b}	29.0 ± 5.2^{a,b}	16.5 ± 1.7^{a}
MIDDLE	32.0 ± 7.5	80.0 ± 4.9	3.7 ± 2.6^{a,b}	15.3 ± 7.2^{a,b}	28.8 ± 10.8^{a,b}	18.0 ± 1.9	59.0 ± 3.4	13.5 ± 1.7^{a,b}	17.0 ± 4.9^{a,b}	18.5 ± 2.2^{a}
LATE	35.0 ± 8.8	76.0 ± 7.6	81.0 ± 6.4	75.0 ± 9.1	22.4 ± 11.4^{a,b}	19.0 ± 1.5	56.5 ± 4.2	65.0 ± 5.2	59.0 ± 6.9	19.0 ± 2.2^{a}
TWICE	35.0 ± 7.6	38.5 ± 9.5^{a,b}	44.0 ± 10.8^{a,b}	19.7 ±7.4^{a,b}	26.6 ± 9.1^{a,b}	15.0 ± 1.1	19.5 ± 1.9^{a,b}	25.0 ± 3.6^{a,b}	9.0 ± 1.0^{a,b}	14.0 ± 1.2^{a}

[a] Treatments that had been mowed prior to the time these data were collected.

[b] Values were statistically significant from the unmowed controls for the same date with $P < 0.05$ in Tukey's honestly significant difference test.

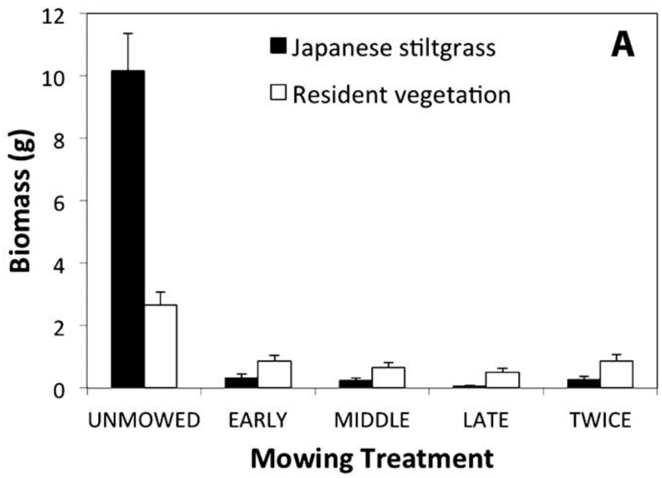
biomass the most, but this was only statistically significant in comparison to the EARLY mowing treatment in 2010.

All mowing treatments, except the 2010 EARLY mowing, also significantly reduced the fall biomass of resident species, which consisted primarily of herbaceous native (and some naturalized) perennials (Figure 1; 2009: $F_{4,145} = 14.19$, $P < 0.0001$, 2010: $F_{5,172} = 5.56$, $P < 0.0001$). Resident biomass was decreased by 67 to 80% in mowed treatments compared to controls in 2009 and by 48 to 84% in 2010. However, resident species recovered a year after the mowing treatments of 2009, and by the end of the growing season in 2010, resident biomass was equal across all treatments and the control ($F_{4,95} = 0.74$, $P = 0.568$). This suggests that mowing every other year may allow the resident plant community to recover from the effects of mowing, which could be advantageous in less extensive invasions of Japanese stiltgrass.

Effect of Mowing Treatments on Japanese Stiltgrass Seed Production. All of the mowing treatments resulted in significantly less seed from all three seed sources, as well as less total seed (Figure 2; CH: $F_{4,145} = 30.73$, $P < 0.0001$; CL: $F_{4,145} = 6.33$, $P < 0.0001$; soil: $F_{4,142} = 54.48$, $P < 0.0001$). There was no statistical difference for any of the seed sources or total seeds among any of the different mowing timings tested. However, CL seed production was marginally lower in the LATE mowing treatment than in the other mowing treatments (Figure 2). This suggests there may be some advantage to mowing later in the season, although the difference was not statistically significant.

Interestingly, there was higher CL seed production in the TWICE mowing treatment compared to the LATE mowing treatment, both of which were mowed on the same date in late August. This may be a result of the first early-season mowing in the TWICE treatment causing the Japanese stiltgrass plants to develop a more prostrate growth habit (Richardson 2011; A. Shelton, personal observation) that may be too low for the mower's cutting height in August. Japanese stiltgrass has a highly plastic growth form in terms of the number and size of tillers it produces (Cheplick 2006, 2007, 2010), and removing the primary tiller may cause it to allocate more resources to lateral tillers. There was no difference in CH seed or soil seed production as a result of timing of mowing (Figure 2). In addition, none of the mowing treatments were able to reduce Japanese stiltgrass production to zero. This suggests that continual management to reduce the seed bank over time will be required.

Seed production was measured in 25 by 25–cm quadrats. Extrapolation to values for a 1-m^2 area range from approximately 1,800 seeds m^{-2} in the LATE mowing treatment to approximately 5,000 seeds m^{-2} in the EARLY mowing treatment. This is much less than the estimated



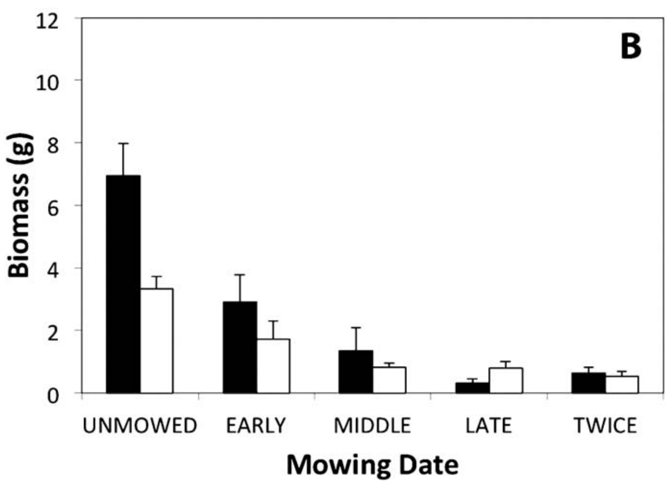


Figure 1. Total mean dry weight biomass (± SE) of Japanese stiltgrass (black bars) and other resident vegetation (white bars). (A) Plots mowed during summer 2009 and harvested in October 2009. (B) Plots mowed in summer 2010 and harvested in September 2010.

19,000 seeds m^{-2} in unmowed plots, and represents a 73 to 91% reduction in seed added to the seed bank annually. These data emphasize the vast quantity of seeds produced by Japanese stiltgrass and the need to reduce seed production by any methods available.

Due to the extensive effort required to adequately measure seed production in Japanese stiltgrass, I only measured seed production in 2009. A regression analysis showed a strong correlation between Japanese stiltgrass biomass and total seed production ($R^2 = 0.78$, $P < 0.0001$), indicating that overall biomass of plants is a good predictor of seed production. Therefore, I consider biomass

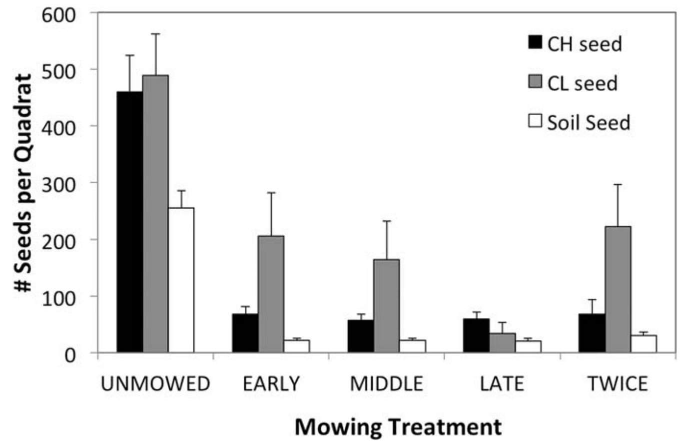


Figure 2. The average (± SE) number of seeds produced by Japanese stiltgrass plants in each 25 by 25–cm quadrat harvested in October 2009. There were significantly fewer chasmogamous (CH) seeds, cleistogamous (CL) seeds, and seeds collected from the top 1 cm of soil (soil seeds) in each of the mowing treatments compared to the controls.

a fairly reliable indicator of mowing efficacy for the 2010 mowing experiment.

Recruitment of Japanese Stiltgrass in the Year after Mowing. Because Japanese stiltgrass is an annual species, the number of plants that grow the year following treatment is another good indicator of treatment success. I measured the number of Japanese stiltgrass stems present in June 2010 and June 2011 in plots subjected to mowing in the previous year and in unmowed controls. All of the mowed treatments in both years, except the EARLY mowing of 2010, had significantly fewer stems than the unmowed controls (Figure 3). The percentage of reduction in the number of Japanese stiltgrass stems in June of the year after mowing was slightly greater for the 2009 mowing than for the 2010 mowing, which was done on plots that were previously mowed in 2009. The number of stems was reduced by 75 to 88% ($F_{4,45} = 13.03$, $P < 0.0001$) for the 2009 mowing and by 66 to 75% ($F_{4,75} = 3.35$, $P = 0.0141$) for the effective treatments in the 2010 mowing. The EARLY mowing treatment of 2010 reduced Japanese stiltgrass stems by only 24%, which was not a statistically significant reduction. There were no statistical differences among the other mowing treatments.

Overall Efficacy of Mowing on Control of Japanese Stiltgrass. The results of these experiments demonstrate that mowing can be an effective control method for Japanese stiltgrass, and the timing of mowing does not have to be restricted to the late summer period just before plants set seed. This challenges the accepted belief that Japanese stiltgrass should only be mowed late in the season in the narrow phenological window between flower production

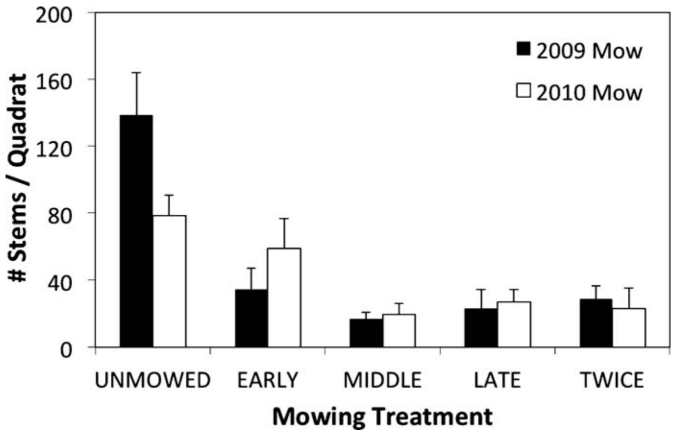


Figure 3. The average number of Japanese stiltgrass stems (± SE) per 25 by 25–cm quadrat in June of the year after mowing. Black bars are for plots mowed in 2009 and stems counted on June 1, 2010. White bars are for plots mowed in 2010 and stems counted on June 17, 2011.

and seed set (e.g., Flory 2010; Richardson 2011; Swearingen 2009). However, mowing before July was less effective than mowing later, and the latest mowing treatment (August 30) reduced CL seed production more than the other mowing timings, although the difference was not statistically significant.

Land managers often do not have the time and resources to mow all areas of Japanese stiltgrass invasions during the approximately 3-wk window between flowering and seed set, and as a result, may choose not to mow at all based on previously published statements that earlier mowing is not as effective. The results presented here demonstrate that although mowing may be slightly more effective when done later in the growing season, mowing any time after June can dramatically reduce seed set and the number of Japanese stiltgrass plants that grow the following year.

The 2010 EARLY mowing treatment, which was done on June 18, may have been less effective than the other mowing treatments for several reasons. First, the 2009 EARLY mow was on July 1, almost 2 wk later than the 2010 EARLY mow. Mowing prior to July may allow Japanese stiltgrass plants to recover before the end of the growing season. Second, if early mowing kills young plants, the remaining plants may experience reduced density and be able to grow larger. Previous studies have reported that Japanese stiltgrass does have density-dependent growth (Brewer 2011). However, seed production does not appear to be reduced at high densities and may be higher for plants that grow in high-density populations (Cheplick 2010). Stem densities at the beginning of June 2010 were less than in 2009 because these plots had been mowed in 2009. This may also allow more rapid growth of the existing Japanese stiltgrass plants.

This study emphasizes that continued treatment over multiple years is required to manage Japanese stiltgrass. Two years after the 2009 mowing treatments, none of the mowing treatments had any difference in percentage of cover or the number of stems compared to the unmowed control. The mowing treatments in 2010 were applied to plots that had been mowed with the same timings used in 2009. Mowing reduced biomass by 97 to 99% in 2009 but by only 58 to 96% in plots that were mowed again in 2010. In addition, the year-end biomass of Japanese stiltgrass was slightly higher in 2010 (0.3 to 3.0 g quadrat^{-1}) than in 2009 (0.1 to 0.3 g quadrat^{-1}), regardless of the timing of mowing. Mowing twice per year did not reduce biomass more than mowing once, and plots mowed twice (EARLY and LATE) had marginally higher seed production than the LATE mowing plots. This suggests that repeated mowing within a year is unnecessary and potentially deleterious. Plants may adapt to repeated mowing by growing more prostrate and closer to the ground, thus allowing them to produce more CL seeds in their leaf axils.

Japanese stiltgrass plants were able to produce some seeds in all of the mowing treatments. Seed production was dramatically reduced by 73 to 91% in 2009, but even plots mowed while plants were flowering (LATE treatment) produced an estimated 1,800 seeds m^{-2}. This suggests mowing is unlikely to eliminate Japanese stiltgrass populations in 1 or even 2 yr, but may gradually reduce the seed bank if continued over multiple years.

Mowing will not be the most effective control strategy for all populations of Japanese stiltgrass. It has significant nontarget effects on native species (Figure 1), although those effects disappeared after 2 yr of mowing. If protection of the native community is not important and the goal is merely to reduce seed production of Japanese stiltgrass (e.g., along roadsides), then annual mowing could be an effective control strategy. If the resident plant community is important, then mowing every other year may allow native species time to recover. However, this would also allow Japanese stiltgrass to produce more seed. A better strategy might be to mow for 3–4 yr to reduce the seed bank of Japanese stiltgrass and then not mow for a year to allow native perennial species to recover.

Grass-specific herbicides have also been shown to be highly effective for controlling Japanese stiltgrass with little deleterious effect on native plants (Flory and Clay 2009; Judge 2005), but herbicides may not be practical for all invasions. In areas where herbicide use is not permitted or where nontarget risks to native plants, animals, or humans are high, mowing may be an effective alternative strategy. Fire has also been used to control Japanese stiltgrass. Fire can kill growing plants and hot fires can kill dormant Japanese stiltgrass seed (Emery et al. 2011). However, many fires do not become hot enough to kill seeds and can result in significant germination of Japanese stiltgrass seeds from the seed bank (S. L. Flory, unpublished data). Flory and Lewis (2009) found that both spring and fall fires reduced biomass of Japanese stiltgrass, but that mowing was more effective than burning. Mowing is most likely to be effective in areas that have high risk of reinvasion by seed, where the seed bank is unlikely to ever be reduced to zero, and in areas that have a high risk of spreading seed to new sites, e.g., along roadsides or stream banks.

It is often difficult to mow large areas of Japanese stiltgrass within the narrow phenological window between the development of flowers and seed set because it is such a short time period, and some land managers may leave populations untreated if they believe the control methods are ineffective. Mowing too late in the growing season can also have risks. The development of CL seeds can be difficult to monitor because they are not visible without checking inside the axillary leaf sheaths. It is unknown if these seeds can continue to mature once they are cut from the plants, so mowing plants that contain maturing CL seed may inadvertently spread seed rather than reduce it. The experiments presented here provide weak support for the importance of mowing Japanese stiltgrass late in the summer or fall just prior to seed set. Mowing any time after early July significantly reduced all measures of Japanese stiltgrass growth and reproduction as effectively as later mowings.

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