Integrated Kudzu Control on Mississippi Roadsides

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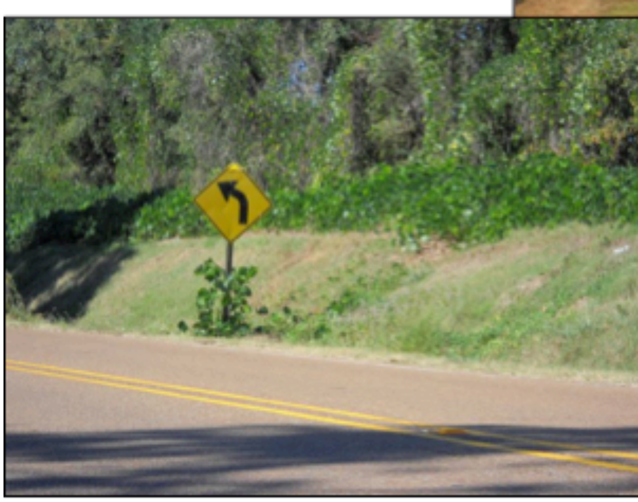

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16. Abstract

Kuzdu is among the top weed threats in Mississippi and is found on may roadsides and right-of-way. The present research evaluated the efficacy of several previously undocumented tools for the eradication of kudzu, including the use of alternative herbicides, the use of the pathogen *Myrothecium verrucaria* and the integration of multiple methods to bring about more rapid kudzu eradication.

Field trials with herbicides were conducted in triplicate at three locations over two years and demonstrated 95% or better control in at least one location with Chaparral, Escort, Milestone, RemedyUltra, Streamline, Transline and Vista, as measured 11 months after initial treatment.

Integrated treatment programs, including various combinations of: broadcast application of Milestone VM+; applications of the bioherbicide *Myrothecium verrucaria*; mowing and spot treatments with Vista and Escort; and planting of switchgrass were all very effective in controlling kudzu. Zero kudzu was detected in many of these treatment plots the following season, and plots planted in switchgrass were well-established.

In a supplemental greenhouse-based experiment, nine herbicides that might be used to aid in transitioning a site from kudzu to native perennial grasses were tested for compatibility with seven grass species. While there were many important specific herbicide-species interactions, many of the kudzu herbicides were well-tolerated by the grasses.

17. Key Words Kudzu; Biological control; *Myrothecium verrucaria*; Integrated weed control; aminopyralid; aminocyclopyrachlor	**18. Distribution Statement**

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Table of Contents

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Introduction

The existence of kudzu (*Pueraria montana*) as a weed in the southern U.S. is a striking manifestation of the law of unintended consequences. Kudzu was hailed variously by farmers, the government and southern horticulturalists as a drought and heat tolerant, productive forage, a means to halt erosion and as a hearty ornamental plant and planted extensively in the early 20th century. The hope placed in kudzu was never fully realized: yield as a forage was sensitive to grazing pressure and kudzu couldn't be successfully baled; it was far better at masking erosion than stopping it; the ornamental value of kudzu was quickly offset by its invasive nature. The most credible estimate of kudzu's prevalence is 7 million acres, increasing at 120,000 acres annually (reviewed in Forseth and Innis 2004).

Direct economic costs are difficult to measure for any weed, and especially so for weeds that infest natural areas. Kudzu undermines the productivity and profitability of timber plantations. Quimby et al. (2003) estimated the direct losses from kudzu at $500 million annually. Another estimate placed the economic damage from kudzu at $54 million annually from lost timber production within the state of Mississippi alone (A. Van Valkenburg, Area Forester, Mississippi Forestry Commission, pers. comm.). Interference with utilities and transportation rights-of-way can present a serious safety hazard as well as an ongoing nuisance. It is impossible to fully measure the damage it causes via disruption of natural ecosystems and displacement of native plants. Kudzu control programs often include herbicides with limited selectivity, high mobility and / or long half-lives resulting in unmeasured environmental damage.

Documented kudzu control techniques

The most popular method for controlling established stands of kudzu is the use of chemical herbicides. Many current kudzu eradication guides are based in large part on the conclusions of James Miller, USDA Forest Service who tested many herbicides and herbicide combinations for efficacy against kudzu (Miller 1985; 1988, 1996). The work of Miller established Tordon and Tordon 101 (picloram and picloram + 2,4-D, respectively) as the herbicides of choice, and also outlined a set of other herbicides with reduced efficacy, but more suitable for some applications where Tordon was not registered. Even with selection of a good herbicide and with appropriate application methods the eradication of mature

kudzu is challenging and typically requires many years of herbicide re-application (Miller 1996).
While the efficacy of Tordon is well established, the use of the herbicide has substantial drawbacks. It is a restricted use product, leading to additional application costs. Tordon is herbicidal to many desirable plant species and may not be applied in established conifer plantations. Most importantly, picloram is both highly persistent in the environment and is mobile in the water column, leading to off-target movement and contamination of groundwater (Berisford et al. 2006). While not as well-documented in peer-reviewed journals, other herbicides commonly used in kudzu control are Transline (clopyralid) and Escort (metsulfuron-methyl). Both of these products offer improved selectivity, allowing their use in some forestry applications. Milestone herbicide (aminopyralid) was registered in 2005 and is labeled for kudzu control, but no published field studies have documented its efficacy. A new active ingredient, aminocyclopyrachlor entered the market in 2011 as Streamline, Perspective and Viewpoint herbicides and have been experimentally tested against many important weeds, but no publications with kudzu have yet emerged.

Other documented means of kudzu management include grazing, mowing, solarization and the manual removal of kudzu crowns below the soil surface. While kudzu was utilized as a forage crop, it is sensitive to overgrazing and to grazing at some times of the year. Grazing intensity must be continuously maintained for 3-4 years at a level of greater than 80% defoliation to achieve eradication (Miller, 1996). Grazing kudzu infested lands can also present significant animal and land management challenges, particularly on areas with steep slopes. On sites with more moderate slopes mowing can provide a high level of kudzu suppression, and, depending on the seed bank and active revegetation efforts, can be a useful step towards transitioning a site to more desirable vegetation. Solarization is a novel means of kudzu control, achieved by covering a site with polyethethylene sheeting resulting in solar-induced heating which eventually kills the kudzu. One year of solarization produced less than 50% control, but a second year resulted in about 97% control. The method is presently considered impractical, but offers some insight into the biology and physiological tolerances of kudzu (Newton et al. 2008). Another labor-intensive approach is the manual removal of kudzu crowns, particularly the ‘surgical’ method where, with a minimum of disturbance, the crown is severed from the deeper roots. This approach has been utilized to achieve eradication on a variety of sites (kokudzu.com last accessed 12/12/2011).

There has been a long and extensive search for an effective biological control agent. In fact, numerous native or naturalized insects have been found on kudzu, some apparently causing significant defoliation, seed, stem and root damage (reviewed in Forseth and Innis, 2004). Kudzu is closely related to many important plants in the Fabaceae family (e.g., soybeans and common beans), so

potential biocontrol agents must undergo host range study to ascertain safety. Kudzu-feeding insects continue to be discovered and evaluated (Sun et al. 2006; Imai et al. 2010).
The most well-studied agent for the biological control of kudzu is the fungal pathogen, *Myrothecium verrucaria*. This fungus is native to the U.S. and is highly virulent when applied with a surfactant to several broadleaf plants (Boyette et al. 2002). There are several reports of toxin production by this fungus (Abbas et al. 2001; Millhollon et al. 2003), but improved methods in fungal mass production and formulation have mitigated this hazard (Boyette et al. 2008; Weaver et al. 2009a). Ongoing research with *M. verrucaria* has revealed compatibility with herbicides (Weaver and Lyn, 2007; Weaver et al. 2009b), synergism with glyphosate (Boyette et al. 2008), and improved efficacy through use of appropriate surfactants (Weaver et al. 2009).

Research objectives

The present research aimed to measure the efficacy of several previously undocumented tools for the eradication of kudzu, including the use of alternative herbicides, the use of the pathogen *Myrothecium verrucaria* and the integration of multiple methods to bring about a more rapid eradication.
Ultimately a kudzu control strategy should aim beyond simply killing weeds and also establish desirable vegetation. With this in mind, additional experiments evaluated the interactions of several herbicides and grass species to consider what species could be effectively established in legacy kudzu sites and which herbicides would be most compatible with revegetation efforts.

Methods

Kudzu field experiments

Study Sites. Four kudzu-infested sites within Mississippi were selected for field research. The Eden site (33° 0'16.73"N 90°15'56.11"W) occurs on the slopes near the edge of the Mississippi Alluvial Delta. The Mound Bayou site (33°52'53.79"N 90°36'44.71"W) is on a river terrace on the west bank of the Sunflower River. The Grenada site (33°55'2.00"N 89°44'42.17"W) is in the Holly Springs National Forest, in the northern right-of-way of Highway 7. The Byhalia site (34°34'415" N, 90°24'525" W) is in a clearing south of highway 304. The four plots span a distance of about 215km. Phase I experiments began at Eden and Mound Bayou experimental sites in 2007 and work began at the Grenada site in 2008. Phase II experiments began at Eden, Mound Bayou and Byhalia in 2010. For consistency and reproducibility, all plots were established on flat to minor slopes with little or no competition from surrounding trees within mature kudzu monocultures. Mowed borders, 2 m wide, were maintained around each plot, which measured 2 m by approximately 15 m. These borders were mowed every 7 to 14 days during the growing season, as needed, to minimize above ground spread of kudzu between plots. Meteorological observations were collected from local weather stations and are available at www.DeltaWeather.MSState.edu (last accessed 12/7/11).

Herbicide and bioherbicide applications. The herbicides evaluated in this study; their commercial formulations and application rates are listed in Table 1. All herbicides were applied at the maximum labeled rates, except Chaparral, which was applied twice per year at half the labeled rate and Streamline, which was applied twice per year at the equivalent of 4.75 oz per acre because the maximum labeled rate was not yet established. Because some products recommend the addition of spray adjuvants, Silwet L-77 was added to all products at a rate of 0.25% (v:v) during phase I treatments. Subsequent research indicated that higher efficacy was achieved with Induce non-ionic surfactant, so it was used in all phase II treatments. All applications were made with an ATV mounted boomless, single-nozzle system (TeeJet TFW-12) with two overlapping passes to deliver a total volume of 40 gallons per acre.

Phase I experiments were conducted at Eden, Mound Bayou and Grenada and consisted of three replicates at each location. Phase II experiments were at Eden, Mound Bayou and Byhalia, consisting of three replicates at each location. Included in Phase I experiments were several post-emergence, foliar herbicides for kudzu control. Phase II experiments included two herbicides from Phase I; two new herbicides, with two application timings: Chaparral-S and –F and Streamline-S and –F for a spring and fall application, respectively. Also included were an organic treatment consisting of application *of M. verrucaria*, mowing and planting of switchgrass; an integrated treatment with an initial application of Milestone VM+ followed by mowing, planting of switchgrass and alternating spot-sprays of *M. verrucaria* and Vista; an integrated treatment identical to the previous, but omitting the mowing; and a chemical intensive treatment that included an initial application of Milestone VM+ followed by spot sprays approximately every 2 weeks of Vista or Escort whenever new growth would emerge. Initial treatments were in June of 2010 for integrated, organic, chemical intensive, Chaparral-S and Streamline-S and in September of 2010 for Milestone, Escort and the Chaparral-F and Streamline-F treatments.

Measurements of kudzu treatment efficacy. All green kudzu biomass was collected in pre-weighed bags from a 0.3 m^2 area, arbitrarily selected within each plot. In plots with very good control, multiple sampling grid placements were necessary to avoid false reporting of 100% control. The biomass was air-dried and the level of control was evaluated based on comparison to the biomass from surfactant-only control treatments. For Phase I experiments, evaluations were made at 14 days, 28 days and 11 months after the initial treatments and 11 months after the applications in the second year of treatment. Phase II experiments, applied in the summer of 2010 were evaluated in June 2011.

Grass tolerance to herbicides. Grasses were grown in 6.4cm x 6.4cm x 7cm deep pots in a 1 : 1 mix of Metro Mix 360 potting mix for eight weeks (from seed) or four weeks (from transplants) before herbicide application. Pots were subirrigated daily. Herbicide solutions were prepared immediately before use. All solutions except RoundUp included 0.25% Induce surfactant. Herbicides were applied at a rate of 187 L / ha (20 gal / acre) via a track-mounted, automated spray chamber set at 20 psi with a 8002E flat fan nozzle. The study included four replicates per treatment / rate and was repeated twice. Four weeks after application of herbicides the plants were visually rated for injury on a five point scale with four points for green, healthy plants and 0 for totally necrotic plants. After ratings, the above-ground plant matter was cut off, dried and weighed to evaluate growth reduction.

Results and Discussion

Phase I Trials with herbicidal control of kudzu

Eden results. The Eden experimental location was very nearly a pure monoculture of kudzu during midsummer of 2007, as is typical of mature kudzu infestations. Fourteen days after the initial application, all of the tested herbicides produced greater than 60% brown-out (Figure 1). Greater differences emerged between treatments at 28 days after treatment. After producing some moderate initial "bleaching" symptoms, the effect of Calisto diminished. In contrast, Milestone, RemedyUltra, Vista and Escort approached 100 % aboveground suppression of kudzu, with a few plots containing zero green tissue. Nearly one year after the initial treatment, those same treatments were still providing strong kudzu suppression while the effect of Calisto was less than 10 % reduction with Roundup and Ignite providing slightly better results. The selectivity of the herbicides was evidenced by the strong emergence of other vegetation, especially little barley (*Hordeum pusillum* Nutt.) and Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot) (data not shown). The aforementioned herbicides, with the exceptions of mesotrione and glufosinate, were reapplied to the same plots in 2008. Transline was also introduced in the study during the second year on previously untreated plots. The level of control noted the following season (summer, 2009) was generally less than observed after the first season of treatment but still over 80 % suppression. Transline provided slightly less reduction in kudzu aboveground biomass in its first season of application. Some possible reasons for the reduced control from the 2008 application compared to the 2007 application are year to year weather differences or that the competing vegetation in the second year prevented through herbicide spray coverage.

Mound Bayou results. Several differences in the control of kudzu were observed at the Mound Bayou site relative to the Eden site (Figure 2). First, Calisto and Ignite were even less effective at Mound Bayou than the weak control they provided at Eden, with Calisto having zero measureable effect the year following application. Also, while the level of brown-out 28 days after treatment was greater than 80 % for six of the herbicides, including glyphosate, and four individual plots had zero observed green kudzu at that time, none of the treatments averaged over 65 % control the following year. During 2008, substantial competing vegetation emerged in the herbicide-treated plots, particularly Johnsongrass (*Sorghum halepense*) (data not shown). After the second year of herbicide application the level of control improved and the same four treatments that were most effective at Eden produced greater than 90 % kudzu reduction at Mound Bayou. The plots treated with PastureGard in the first year and Transline in the second year had statistically similar results to the other effective treatments. Roundup was less effective, giving only 64 % suppression after two years of application.

Grenada results. Results from the Grenada site generally support the results from the previous two locations (Figure 3). While Milestone and Vista were statistically less effective in immediate kudzu suppression, all four herbicides provided 95 % or better control 11 months after the initial application. The 2010 evaluation point, 11 months after the second annual application, validated the excellent kudzu suppression provided by Escort, Milestone and Transline and a highly variable, lesser degree of control by Vista. All four products achieved 100% control in at least one of the three replicates. The Grenada site was very close to highway 7, and discussion with the Mississippi Department of Transportation suggested that the site has been mowed in previous years. These previous disturbances may have undermined the vigor of the kudzu at this location, thus enhancing the control provided by the herbicide treatments.

The high level of kudzu control with just a single application of Escort, Transline and RemedyUltra herbicides might be somewhat surprising in the context of other published reports (e.g., Miller, 1996), which suggested that these products only provided moderate suppression. Furthermore, the effectiveness of Milestone and Vista has not been documented, and kudzu does not even appear on the list of weeds on the Vista label. It is possible that in the present study the local climatic conditions were especially favorable for control; however, similar results were obtained at 3 locations over 2 years. The commercial triclopyr product evaluated in these studies, RemedyUltra, was a new formulation, which might have improved the efficacy of this chemical. A more likely explanation, however, is the nearly ideal application conditions in the present study. In order to maximize reproducibility and control, all the plots were on fairly open, nearly level ground and all herbicides were applied with an ATV-mounted, high-volume boomless nozzle system. This methodology likely produced more complete and uniform coverage than might be routinely achieved with hand-held sprayers.

Phase I conclusions

The results from the Phase I experiments support the conclusion that there are several herbicides that are highly effective in suppressing kudzu. While the level of suppression varied somewhat across years and locations, the highest tier of control was consistently achieved with Escort and Milestone. The control achieved with Milestone is noteworthy, as this product has not been previously documented for use on kudzu, is very affordable (less than $25 / acre), and is recognized by the EPA as a “reduced risk” herbicide. Transline, RemedyUltra and PastureGard also were highly effective and use of these products lead to eradication in some plots. The most variable results were obtained with Touchdown. Use of this herbicide may be especially sensitive to application timing or soil moisture conditions.

Phase II Kudzu field experiments

Planning of Phase II experiments. Concurrent with the Phase I experiments, there were other developments relevant to kudzu control: First, there were a series of discoveries that lead to safer and more productive systems to grow the biological control agent, *M. verrucaria* (Boyette et al., 2008; Weaver et al., 2009a) and use it in conjunction with other herbicides (Weaver and Lyn, 2007; Weaver et al. 2009b). Some success was demonstrated in field trials with *M. verrucaria* alone and in co-application with herbicides. Chaparral, a new formulation of aminopyralid plus metsulfuron entered the market at an attractive price (less than $17 / acre at full retail price). Weed scientists were discussing results with experimental formulations from DuPont, which were commercialized in 2011 as Streamline, Viewpoint and Perspective. In this context, the Phase II experiments were developed to evaluate the new herbicides; test biological control strategies; and integrated control techniques, which included *M. verrucaria*, herbicides, mowing and revegetation. An additional goal was to bring about the eradication of kudzu more rapidly and through use of alternating modes of action to prevent the emergence of herbicide resistance.

Herbicide treatments. Chaparral and Streamline were tested as split applications; the –S treatments were applied at half rate in the spring and then half rate in the fall while the –F treatments were applied at half rate in the fall and then at half rate the following spring, immediately after the rating. The Streamline-S treatments were especially effective (Figures 4-6). Across the three locations, the suppression with the Streamline-S treatment ranged from 95 to 100% and zero kudzu was detected at 5 of the 9 plots. The Streamline-F treatment ranged from 82 to 97% with no observed kudzu observed in 3 of 9 plots. The other single herbicide treatments, Chaparral, Escort and Milestone, all resulted in good first-season control, but did not result in as many plots with 100% control. The chemical intensive treatment, which was an initial Milestone VM+ treatment followed by alternating Escort and Vista spot treatments resulted in 94 to 100% control, but also failed to achieve eradication as often as the Streamline-S treatment.

Integrated treatments. None of the integrated treatments gave less than 88% control at any of the locations, and many resulted in localized eradication (Figures 4-6). All of the integrated treatments also included the establishment of switchgrass, a native perennial that is useful for erosion control and potentially as a biofuel crop. There was no supplemental water added to the sites after the June hand planting, and even with the very dry summer in 2010 there was almost 100% survival and good seed production (Figure 7). In 2011, volunteer switchgrass was observed in some plots and in plot borders. Planting switchgrass was easier in mowed plots than in unmowed, but there was no measured difference in grass establishment.

The biological control agent, *M. verrucaria* and the herbicides in these treatments, Milestone VM+, Escort and Vista, did not result in any injury to the grass. The organic treatments are especially interesting as there are no other replicated, multi-site tests demonstrating the effectiveness of similar treatments. This organic regimen, consisting of a single mowing event in June, followed by *M. verrucaria* spot treatments in the growing season and planting of native grass resulted in 92% control across all three locations. This could be an attractive treatment program in sites where erosion is a significant concern or where the chance of contamination of adjacent surface water precludes herbicide application.

Phase II conclusions

The rapid transition from kudzu to alternative vegetation is visible in Figure 8. Those photos make clear the different outcomes that are possible based on management practices over a short (4 month) period. The observations of the Phase II experiments support the hypothesis that there are multiple strategies that will reliably produce ≥ 90% kudzu suppression, as measured in the following year. All of the tested programs resulted in ≥ 90% kudzu biomass reduction in at least two of the three locations. Treatments that included revegetation required additional labor, and some programs involved repeated scouting and occasional spot application of herbicides or bioherbicides. While the organic and integrated plots were scouted on a weekly basis, most observations did not detect any living kudzu, so no treatments were used.

Given the success observed with use of these herbicides and combination treatments, the selection of a kudzu eradication program can be driven by many factors beyond simple efficacy. Other important factors are the potential for erosion at a site and the desired replacement vegetation.

Phase III Tolerance of grasses to selected herbicides

Planning of Phase III experiments. Several herbicides and integrated control methods were successful in controlling kudzu, but in some cases the plots were then overtaken by other weeds. For example, all the Mound Bayou plots that had herbicide treatments were rapidly colonized by Johnsongrass. Other published reports and indications from the herbicide manufacturers suggested that at least some grass species should be tolerant of many of the tested herbicides, but the level of tolerance was often unclear and tolerance for some desirable grass species was unknown. Phase III experiments were developed to test seven grass species for tolerance to the same herbicides that were being evaluated in the field for kudzu control. Outrider and Telar were also included because they are known to selectively control Johnsongrass while being tolerated by some other grass species.

Results. Examples of well tolerated, moderately well tolerated and not well tolerated herbicide interactions are presented in figure 9. Many of the herbicides evaluated for kudzu control were well-tolerated by the grass species tested (Table 3) even at levels well above the maximum labeled rate. This tolerance for elevated rates provides a level of safety in the case of inadvertent spray pattern overlap or errors in application that can occur with uneven terrain. For example, Milestone and Streamline herbicides resulted in substantial visual injury only on one species (Buffalo grass) and 50% or greater reduction in biomass on only one or two species, respectively, even when tested at up to 4x labeled rates. Imprelis is no longer on the market, and was never labeled for use in pastures, rangeland, forestry or roadsides. It was included because the active ingredient in Imprelis, aminocyclopyrachlor is also in other products that are recommended for kudzu control, including Perspective, Streamline and Viewpoint. Because Imprelis was labeled for turf professionals, it is not surprising that it was well tolerated by the tested grasses. It produced visual rating scores ≤ 2 only on buffalo grass and Indian grass, and then only when applied at 2x or 4x the labeled rate. Even with this over-application there was ≤ 33% reduction in dry shoot weight.

Selective herbicidal control of Johnsongrass can be difficult. Outrider was tested because it is one of the few herbicides recommended for Johnsongrass and is labeled for roadside application. At a 1x rate (2 oz / acre), no injury worse than 2.0 was observed on any of the grasses, and even at a 4x rate, only miscanthus scored 2.0, and none of the grasses had major dry weight reductions at the tested concentrations. Telar is often used for weed control in pastures, rangelands and roadsides, and is labeled for use on buffalo grass, Indian grass and switchgrass but its compatibility with other grasses was unknown. In the greenhouse tests, all species tolerated up to a 2x rate (1 oz / acre) without major visual injury and only switchgrass had substantial dry weight reductions at 1x and 2x use rates.

Roundup Weathermax was also tested against the seven grass species. Even low use rates produced significant visual injury and greater than 50% loss in dry weight. There was a high degree of browning on some leaves of Miscanthus, but relatively little loss in dry weight, and four weeks after treatment the plants appeared to be recovering.

Phase III conclusions

The same herbicides that were shown to be effective in phase I and II experiments were generally well tolerated by big bluestem, buffalo grass, Indian grass, little bluestem, miscanthus, switchgrass and zoysia. Some herbicides, especially at higher than recommended usage rates, produced measurable injury, but severe stunting or necrosis was uncommon. Through appropriate herbicide selection and application at the correct rates the establishment of desirable grass species is possible even during an active kudzu eradication program.

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Disclaimer

Mention of trade or commercial names is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U. S. Department of Agriculture.

Sources of materials

Except where noted above, herbicides were purchased locally from Crop Production Services.

Seed of switchgrass, Indian grass, big bluestem and little bluestem were purchased from Turner Seed, Breckenridge, TX.

Vegetative material of zoysia and buffalo grass was purchased from Todd Valley Farms, Mead, NE.

Vegetative material of sterile miscanthus was purchased from Todd Valley Farms, Mead, NE.

Metro Mix 360 Sun Gro Horticulture, Bellevue, WA, USA.

Induce surfactant Helena Chemical Company, Collierville, TN, USA.

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Table 1 Foliar, post-applied herbicides and rates of application

Herbicide	Commercial product tested [1]	Mode of action	Application rate [2] (% solution)
Aminopyralid	Milestone	Synthetic auxin	0.51 L / ha 7 oz / acre (0.14%)
Aminopyralid + metsulfuron	Chaparral [3]	Synthetic auxin + acetolactate synthase inhibitor	231 g / ha 3.3 oz / acre (0.06%)
Aminopyralid + triclopyr	Milestone VM+	Synthetic auxin	10.53 L / ha 5 qt / acre (2.8%)
Aminocyclo-pyrachlor	Imprelis	Synthetic auxin	260 mL / ha 4.5 fl oz / acre (0.07%)
Aminocyclo-pyrachlor + metsufuron	Streamline [4]	Synthetic auxin + acetolactate synthase inhibitor	134 g / ha 4.75 oz / acre
Chlorsulfuron	Telar	acetolactate synthase inhibitor	35 g /ha 0.5 oz / acre
Clopyralid	Transline	Synthetic auxin	1.56 L / ha 1 1/3 pint / acre (0.4%)
Fluroxypyr	Vista	Synthetic auxin	3.12 L / ha 2 2/3 pint / acre (0.8%)
Fluroxypyr + Triclopyr	PastureGard	Synthetic auxin	9.35 L / ha (2.5%)
Glufosinate	Ignite	Glutamine synthetase inhibitor	2.05 L / ha (0.55%)
Glyphosate	Touchdown or	EPSP synthase	9.34 L / ha

	RoundUp Weathermax	inhibitor	1 gal / acre (2.5%)
Mesotrione	Calisto	HPPD inhibitor	0.219 L / ha (0.06%)
Metsulfuron	Escort	Acetolactate synthase inhibitor	280 g / ha 0.25 lb / acre (0.075%)
Sulfosulfuron	Outrider	Acetolactate synthase inhibitor	140 g /ha 2 oz / acre
Triclopyr	RemedyUltra	Synthetic auxin	9.35 L / ha (2.5%)

[1] Mention of trade or commercial names is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U. S. Department of Agriculture.
[2] Application rate determined by the label directions and expressed as formulated commercial product per hectare. Application concentration based on a 374 L / ha^{-}application volume.
[3] Chaparral maximum use rate is 3.3 oz per product per acre pre year. In the present study it was used at half this rate, twice per year.
[4] Commercial formulations of Streamline were not available at the time of the experiments, so experimental formulations of the active ingredients were use. Streamline maximum use rate is 11.5 oz per product per acre pre year. In the present study it was used at 4.75 oz / acre, twice per year.

Table 2. Grass species and properties.

Species	Origin	Propagation	Other notes
Indian grass *Sorghastrum nutans*	Native US	Seed	
Big Bluestem *Andropogon gerardii*	Native US	Seed	
Little Bluestem *Schizachyrium scoparium*	Native US	Seed	
Switchgrass *Panicum virgatum*	Native US	Seed	Commonly used for erosion control. Potential use as biofuel crop
Buffalo grass *Bouteloua dactyloides*	Native US	Vegetative	
Zoysia *Zoysia matrella*	Asia	Vegetative	Considered a turf species in the US, but used on roadsides in Japan
Miscanthus *Miscanthus x giganteus*	Asia	Vegetative	A sterile relative of the invasive weed, *Miscanthus sinensis*. Potential as a very highly productive biofuel crop

Table 3. Tolerance of grasses to selected herbicides.

	Roundup WeatherMax (glyphosate) concentrations[1]									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings[2]					Dry Weight Reduction[3]				
Miscanthus	4.0	2.9	1.6[4]	1.1		0	34	38	34	
Buffalo	4.0	2.5	1.8	1.5		0	10	37	44	
Switchgrass	4.0	2.0	0.5	1.3		0	62[5]	71	98	
Indian	4.0	2.5	1.5	1.0		0	56	97	97	
Big Bluestem	4.0	2.3	2.4	1.0		0	64	56	70	
Little Bluestem	4.0	1.6	0.6	1.3		0	38	30	27	
Zoysia	4.0	3.0	1.5	1.3		0	42	50	53	

	Milestone (aminopyralid) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	3.0	2.9	3.0	2.5	0	12	0	16	2
Buffalo	4.0	3.0	2.0	1.8	1.1	0	30	17	15	17
Switchgrass	4.0		3.9	3.5	2.8	0		33	48	36
Indian	4.0		3.4	3.3	3.0	0		34	46	29
Big Bluestem	4.0		3.6	2.8	3.0	0		39	19	
Little Bluestem	4.0		3.5	2.5	3.0	0		30	26	
Zoysia	4.0	4.0	3.5	3.4	3.3	0	13	7	19	20

	Milestone VM+ (aminopyralid + triclopyr) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	3.0	2.9	2.6	2.3	0	30	17	10	15
Buffalo	4.0	2.4	2.4	1.1	0.0	0	19	25	28	41
Switchgrass	4.0	2.9	2.1	2.6		0	18	41	24	
Indian	4.0	3.5	2.8	2.6		0	30	53	25	
Big Bluestem	4.0	2.8	3.3	2.1		0	19	21	42	
Little Bluestem	4.0	2.5	2.6	2.6		0	24	30	40	
Zoysia	4.0	3.5	2.9	2.9	2.0	0	5	32	39	

Table 3 continued

	Chaparral (aminopyralid + metsulfuron) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	3.0	3.0	3.0	2.8	0	0	19		21
Buffalo	4.0	4.0	3.5	3.4	3.8	0	3	7	10	0
Switchgrass	4.0		3.6	3.1	3.4	0		16	0	0
Indian	4.0		3.0	2.5	2.8	0		63	66	28
Big Bluestem	4.0		3.0	2.5	3.3	0		24	50	55
Little Bluestem	4.0		3.5	3.0	3.1	0		7	50	43
Zoysia	4.0	4.0	4.0	4.0	3.5	0		84	59	51

	Escort (metsulfuron) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	3.0	3.0	2.9	3.0	0	1	8	1	17
Buffalo	4.0	3.3	3.3	3.5	3.0	0	14	18	10	8
Switchgrass	4.0	3.0	2.4	3.0	2.5	0	0	39	35	5
Indian	4.0	3.1	2.9	3.0	2.8	0	37	52	37	40
Big Bluestem	4.0	3.8	3.1	3.4		0	24	7	27	
Little Bluestem	4.0	3.0	3.3	3.0	2.0	0	0	20	26	
Zoysia	4.0	3.5	3.3	3.5	3.0	0	39	20	55	14

	Streamline (aminocyyclpyrachlor +metsulfuron) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	3.0	2.9	2.8	2.5	0	24	31	1	16
Buffalo	4.0	3.0	2.4	2.3	2.0	0	0	2	0	19
Switchgrass	4.0	3.0	2.9	2.8		0		27	41	63
Indian	4.0	2.3	2.6	2.6		0		61	82	
Big Bluestem	4.0	3.8	2.5	2.5		0		21	37	27
Little Bluestem	4.0	3.8	3.6	3.0		0		38	55	85
Zoysia	4.0	3.0	3.5	3.3	2.8	0	6	1	5	24

Table 3 continued

	Imprelis (aminocyclopyrachlor) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	2.8	2.8	2.5	2.5	0	12	33	27	35
Buffalo	4.0	3.0	2.5	1.5	1.5	0	11	13	22	28
Switchgrass	4.0	4.0	3.3	3.5	2.9	0	0	8	16	4
Indian	4.0	4.0	3.4	3.0	2.0	0	19	0	0	0
Big Bluestem	4.0	3.3	3.4	2.8	3.0	0	11	17	2	21
Little Bluestem	4.0	3.5	3.5	3.4	3.0	0	32	14	17	20
Zoysia	4.0	3.5	3.4	3.4	3.5	0	9	29	26	31

	Outrider (sulfosulfuron) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	3.0	2.8	2.0		0	12	0	13	
Buffalo	4.0	4.0	3.5	3.5		0	0	8	8	
Switchgrass	4.0	4.0	3.5	3.4		0	0	0	7	
Indian	4.0	4.0	3.9	3.8		0	0	14	37	
Big Bluestem	4.0	3.3	2.9	2.9		0	13	9	0	
Little Bluestem	4.0	3.5	3.5	3.6		0	0	41	0	
Zoysia	4.0	3.8	3.5	3.8		0	0	30	14	

	Telar (chlorsulfuron) concentrations									
	0x	0.5x	1x	2x	4x	0x	0.5x	1x	2x	4x
	Visual ratings					Dry Weight Reduction				
Miscanthus	4.0	3.5	3.5	3.4		0	28	22	18	
Buffalo	4.0	3.8	3.0	2.8		0	13	0	3	
Switchgrass	4.0	3.8	2.5	2.1		0	0	53	48	
Indian	4.0	3.8	3.0	2.4		0	0	11	10	
Big Bluestem	4.0	4.0	3.9	4.0		0	0	25	5	
Little Bluestem	4.0	3.5	3.5	3.5		0	24	10	29	
Zoysia	4.0	4.0	4.0	3.5		0	19	8	26	

1 Concentrations are expressed relative to the maximum use rate (table1).
2 Visual ratings based on 0 to 4 scale with 4 = healthy green plants and 0 = total necrosis.

3 Dry weight reduction is expressed on a percentage basis of shoot weight compared to the untreated control.
4 Visual ratings in red highlight values ≤ 2.0; i.e., plants with the worst injury.
5 Dry weight reductions in red highlight values ≥ 50; i.e., plants with the greatest losses in aboveground dry weight.

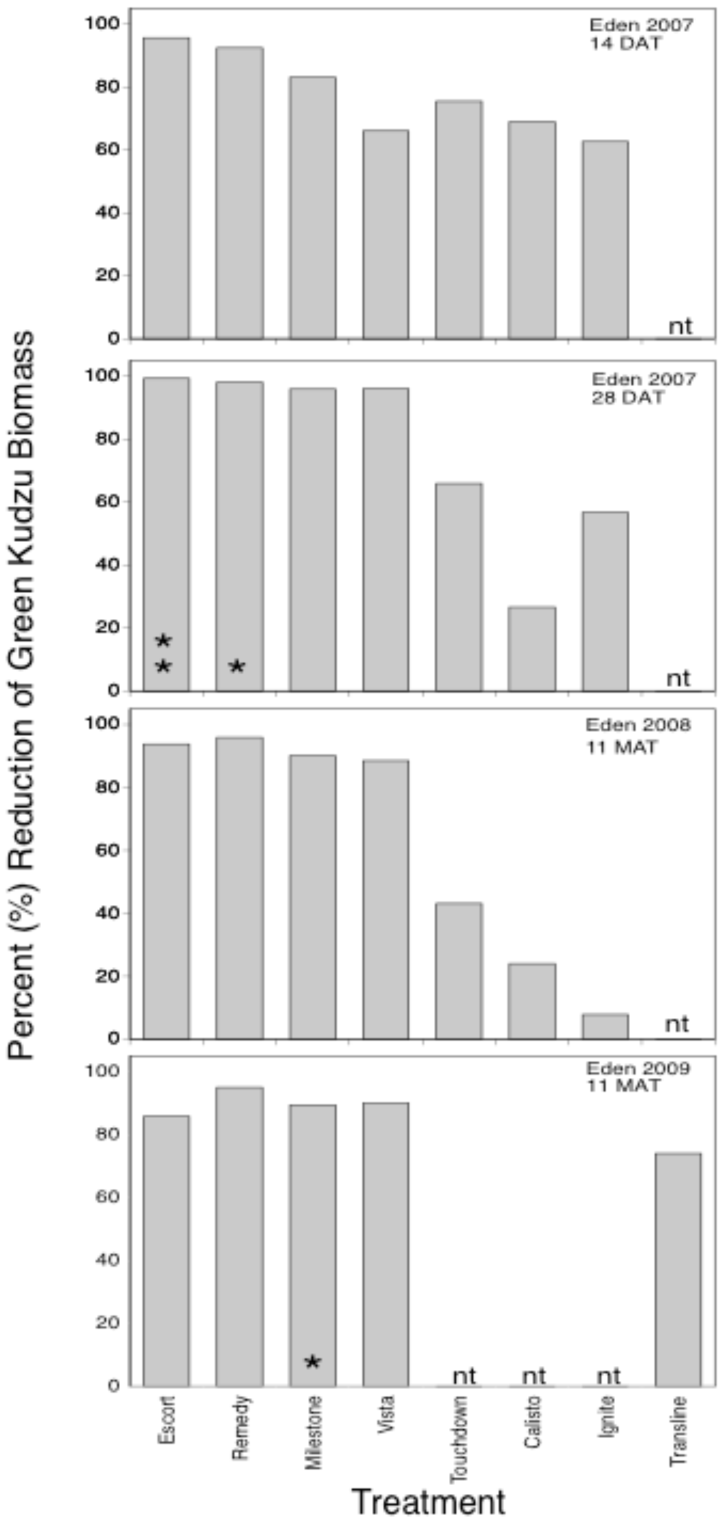

Figure 1. Kudzu control in Phase I experiments at Eden, MS. Asterisks indicate the number of plots with no observable kudzu at the time of measurement. MAT and DAT indicate months and days after treatment, respectively. “nt” indicates a treatment that was not tested at that time point.

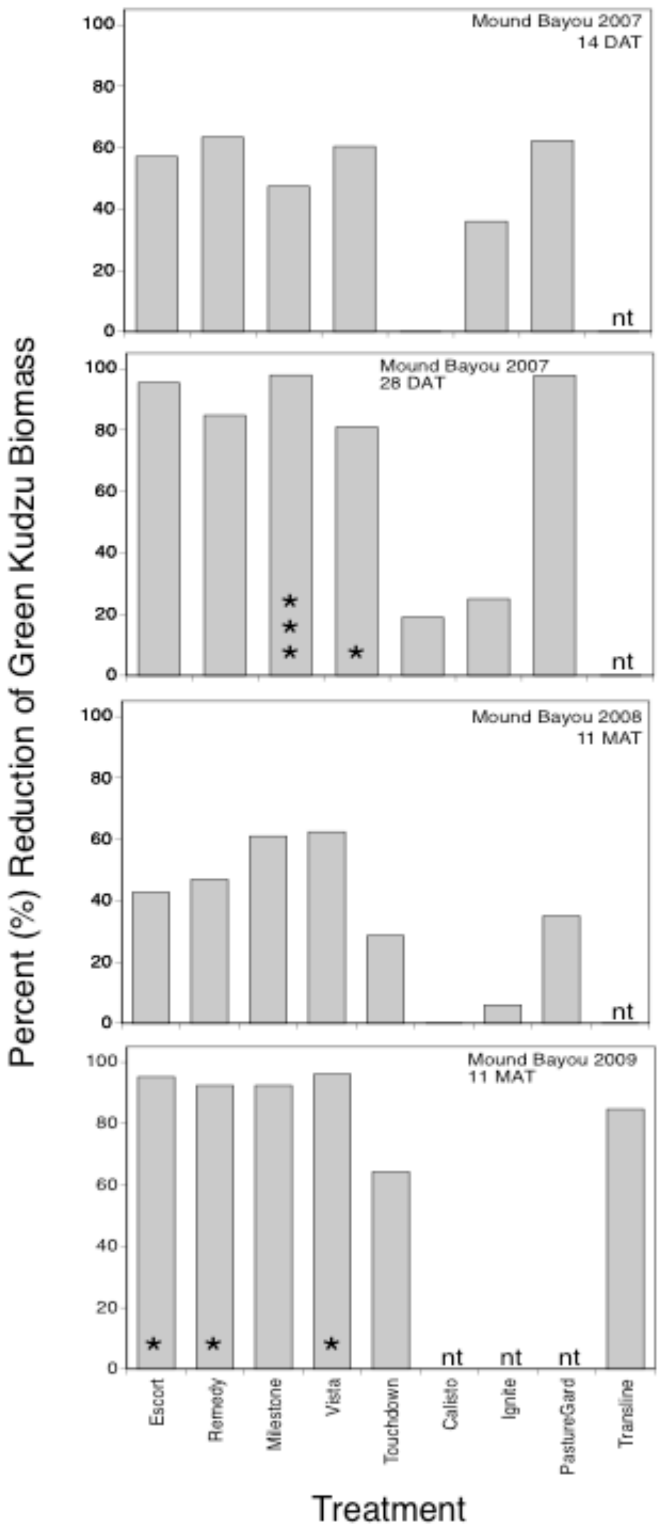

Figure 2. Kudzu control in Phase I experiments at Mound Bayou, MS. Asterisks indicate the number of plots with no observable kudzu at the time of measurement. MAT and DAT indicate months and days after treatment, respectively. “nt” indicates a treatment that was not tested at that time point.

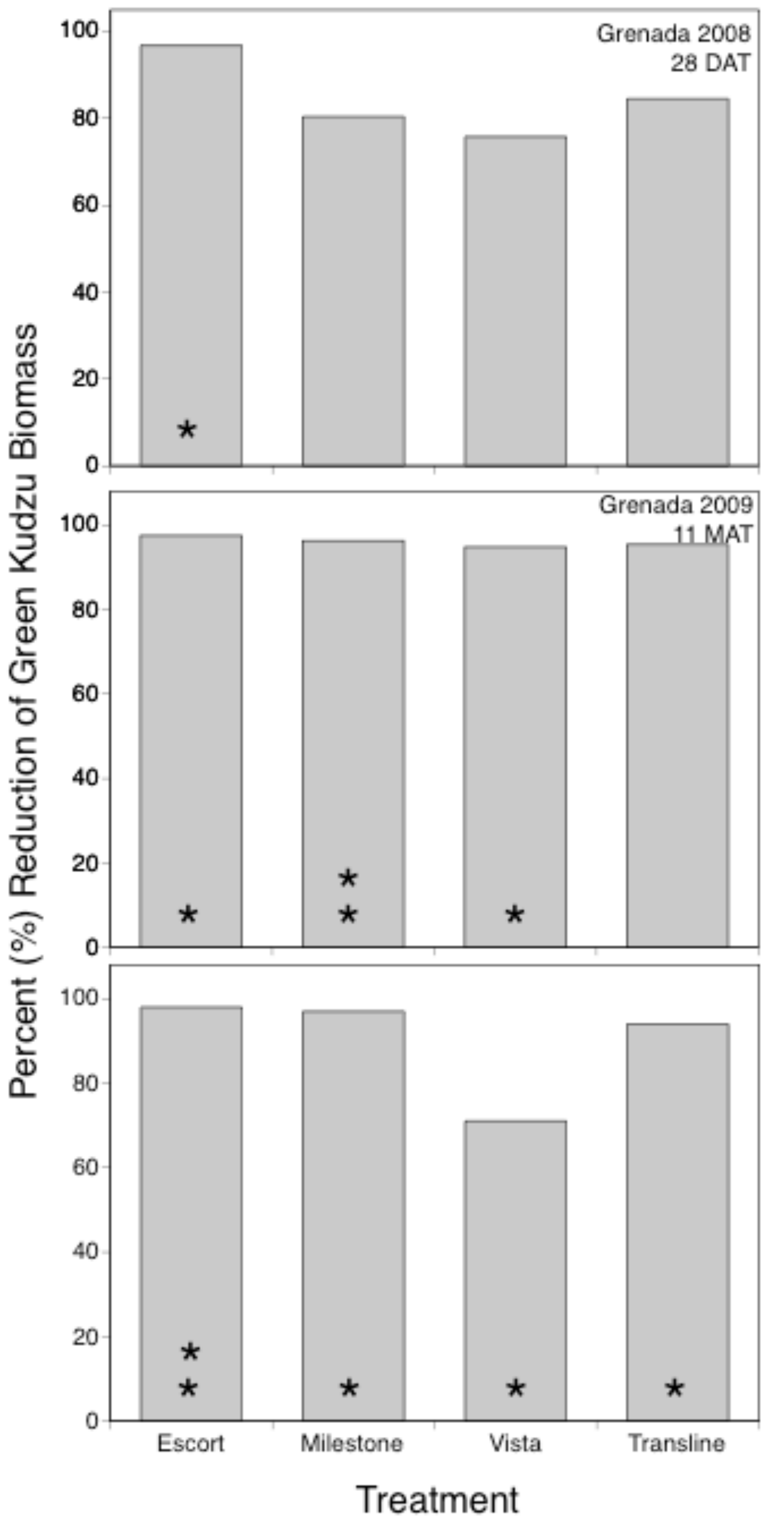

Figure 3. Kudzu control in Phase I experiments at Grenada, MS. Asterisks indicate the number of plots with no observable kudzu at the time of measurement. MAT and DAT indicate months and days after treatment, respectively. “nt” indicates a treatment that was not tested at that time point.

Figure 4. Early symptom development after application of herbicides on kudzu in Eden, MS. Top photo depicts the establishment of individual treatment plots by repeated mowing. The lower photo is of the same plots two weeks after treatment showing (highlighted plots, left to right) a control plot, Escort treatment, Calisto treatment, a control plot and an Escort treatment.

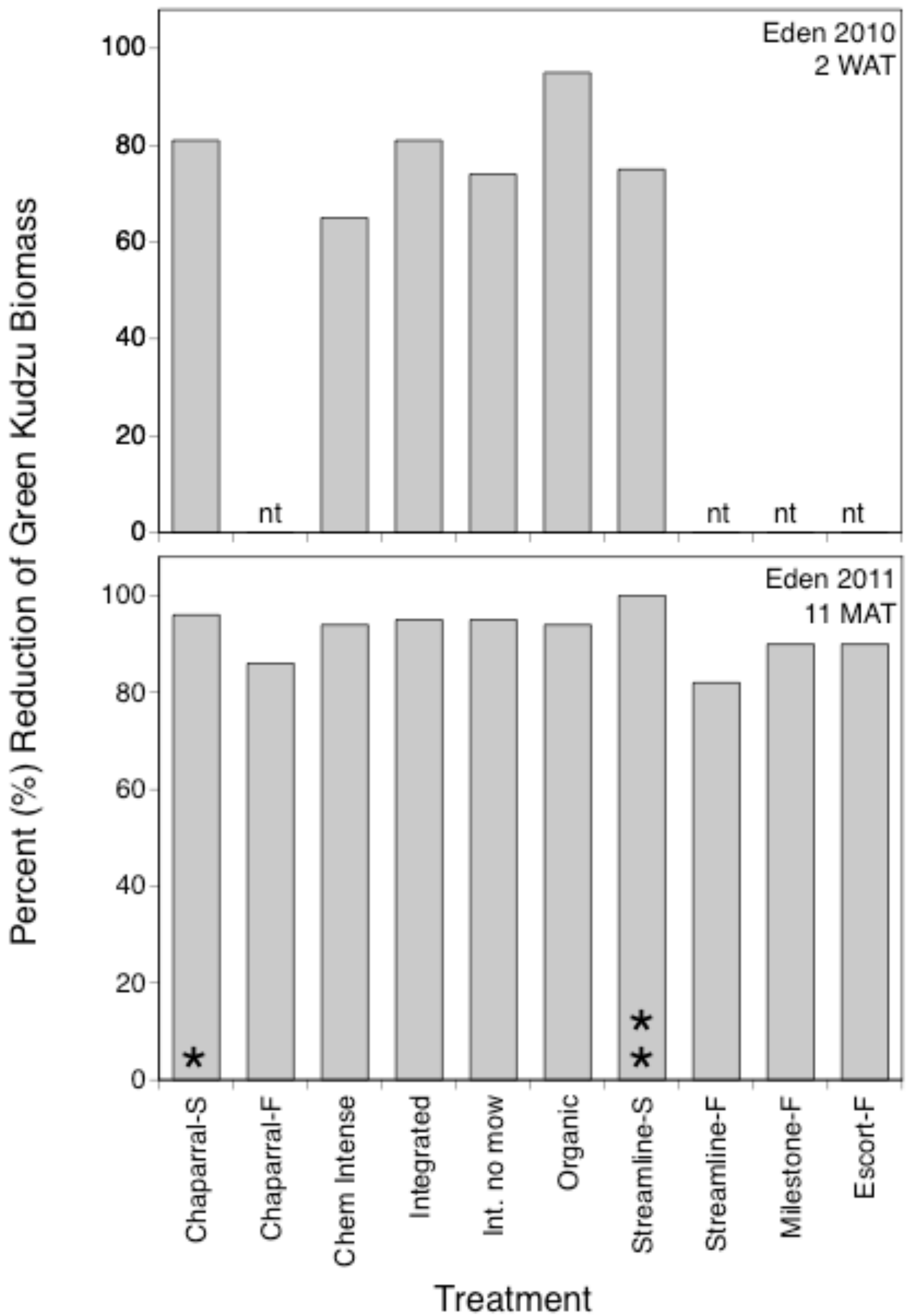

Figure 5. Kudzu control in Phase II experiments at Eden, MS. Asterisks indicate the number of plots with no observable kudzu at the time of measurement. MAT and WAT indicate months and weeks after treatment, respectively. “nt” indicates a treatment that was not tested at that time point. Spring and fall treatments denoted by –S and –F respectively. Other treatments included multiple applications.

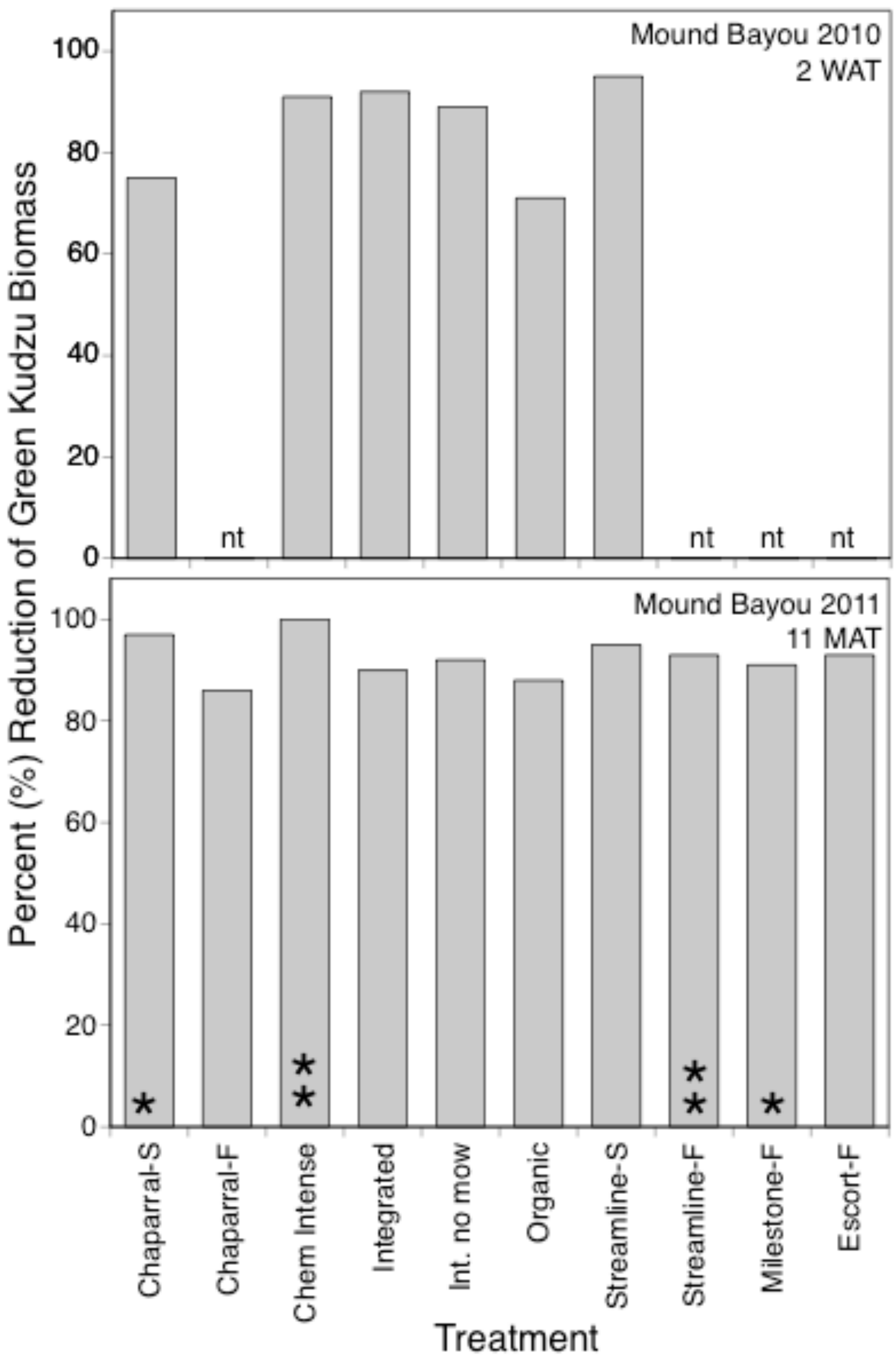

Figure 6. Kudzu control in Phase II experiments at Mound Bayou, MS. Asterisks indicate the number of plots with no observable kudzu at the time of measurement. MAT and WAT indicate months and weeks after treatment, respectively. "nt" indicates a treatment that was not tested at that time point. Spring and fall treatments denoted by –S and –F respectively. Other treatments included multiple applications.

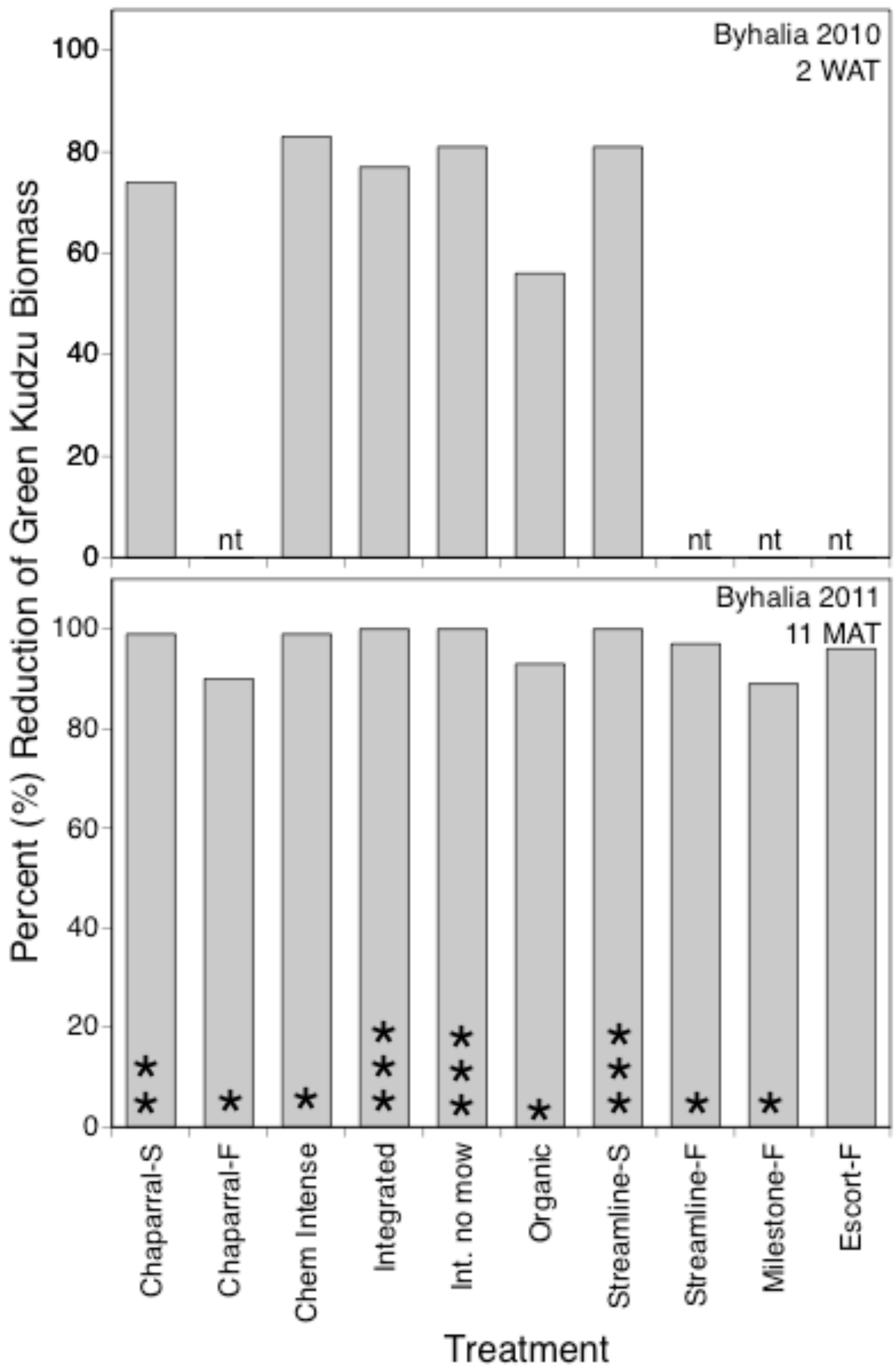

Figure 7. Kudzu control in Phase II experiments at Byhalia, MS. Asterisks indicate the number of plots with no observable kudzu at the time of measurement. MAT and WAT indicate months and weeks after treatment, respectively. "nt" indicates a treatment that was not tested at that time point. Spring and fall treatments denoted by –S and –F respectively. Other treatments included multiple applications.

Figure 8. Establishment of kudzu eradication trials at Byhalia, MS. Top photo is of the test site in June 2010 as the plot borders were being cut out. Lower photo is of the same site in September 2010. At the later date switchgrass is well established and blooming while other untreated and herbicide-treated plots are recognizable.

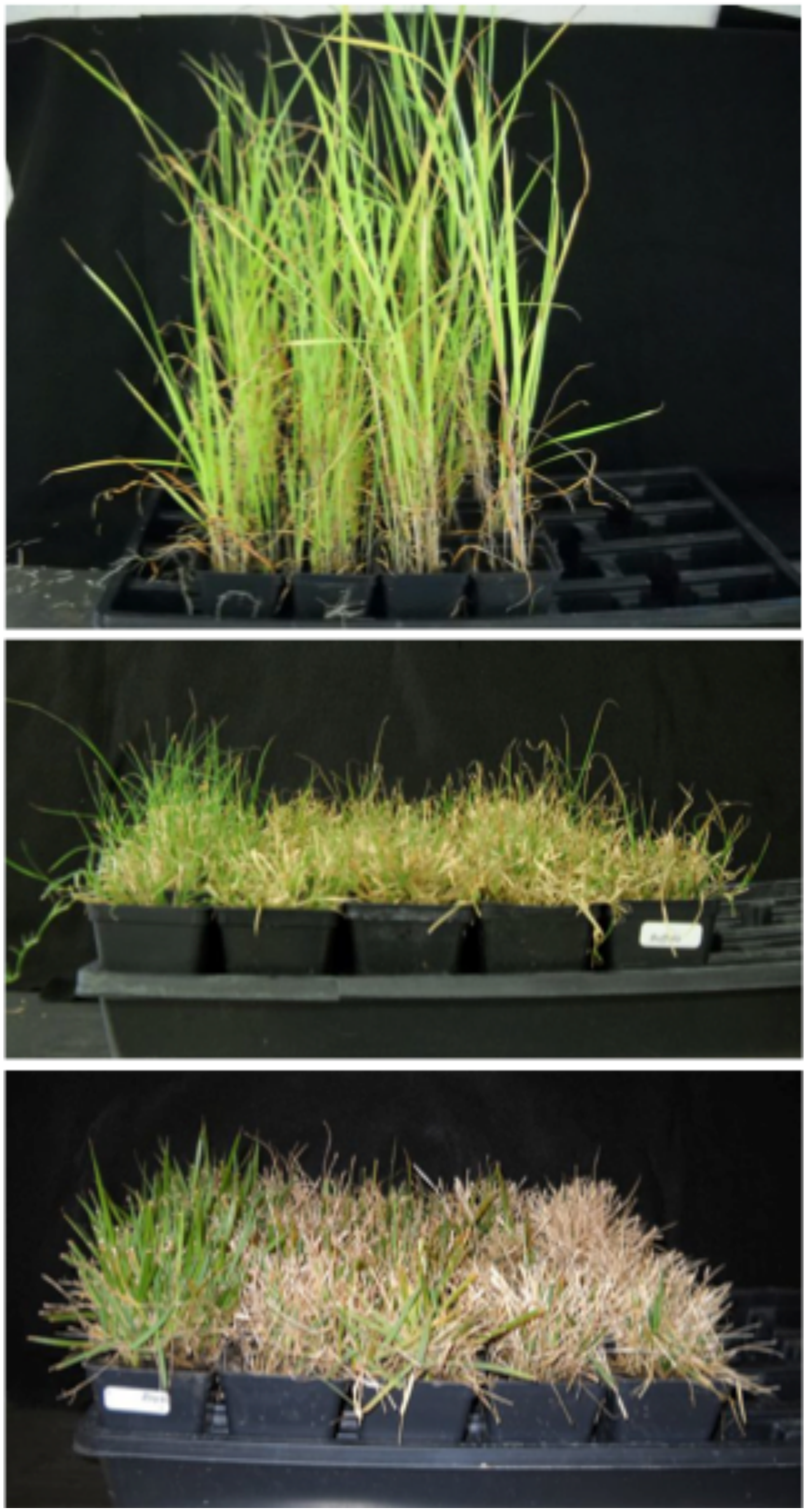

Figure 9. Grass and herbicide interactions. Examples of well tolerated, moderately well tolerated and not well tolerated herbicide interactions, from top to bottom: Chaparral on switchgrass, Streamline on buffalo grass and Roundup Weathermax on zoysia.