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SHORT COMMUNICATION

Management of kudzu by the bioherbicide, *Myrothecium verrucaria*, herbicides and integrated control programmes

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ABSTRACT
Replicated field plots were established and monitored for two years to evaluate management practices for kudzu. The bioherbicidal plant pathogen, *Myrothecium verrucaria*, several herbicides and a variety of integrated control programmes achieved a high level of kudzu suppression, although no system tested reliably achieved eradication in this time frame.

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Kudzu, *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S. Almeida is an exotic invasive weed that is now widespread throughout the southern USA, inflicting great damage in timber plantations, rangeland and natural areas. This semi-woody, vining perennial weed can be very difficult to control, in part because effective herbicides are expensive and have substantial use restrictions (Forseth & Innis, 2004; Nelson, 2003). The fungal plant pathogen, *Myrothecium verrucaria* (Alb. & Schwein.) Ditmar:Fr. (MV isolate IMI 361690) has been identified as a highly virulent bioherbicide of several important weeds, including kudzu. A series of important advances have improved the potential utility of MV. First, the compatibility of MV was determined for several common herbicides (Weaver & Lyn, 2007). Next, improvements in the production techniques facilitated the production of MV without contaminating mycotoxins (Boyette, Weaver, Hoagland, & Stetina, 2008; Weaver, Hoagland, Boyette, & Zablotowicz, 2009). The resulting bioherbicide retained virulence (Weaver, Boyette, & Hoagland, 2012) and was effective in killing kudzu (Boyette, Hoagland, Weaver, & Stetina, 2014). At the same time, new herbicides have been developed for kudzu control with potential improvements in efficacy and selectivity (Minogue, Enloe, Osiecka, & Lauer, 2011; Molin & Lyn, 2012; Weaver, Hoagland, & Boyette, 2015). The objective of the present study was to evaluate the efficacy of MV as a bioherbicide for kudzu in field conditions by monitoring reductions in biomass in subsequent years. Because of the recent developments in herbicidal control of kudzu, new herbicides and a standard herbicide were also evaluated in these field plots. Additional treatments compared the efficacy of mowing and integrated management programmes.

Plots were established within naturally established stands of kudzu in the Holly Springs National Forest, Yalobusha County, Mississippi. While kudzu often occurs as

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monoculture, and kudzu completely and uniformly covered this site during the summer, this site also had elderberry (*Sambucus simpsonii* Rehd); blackberry (*Rubus* sp.); in the study area and Canadian horseweed (*Conyza canadensis* (L.) Cronquist) and stinking chamomile (*Anthemis cotula* L.) at the margins. Plot management and herbicide application was as described elsewhere (Weaver et al., 2015). Briefly, each plot was 2 m wide and at least 20 m long with 2 m wide mowed borders. Plots were situated on flat to moderate slopes away from trees to minimise interference and in an area of uniform vegetation. Treatments were imposed in triplicate in a randomised complete block design; however some plots were lost in the second year due to maintenance activities in the forest. Plot borders were mowed every ~10 days during the growing season to preclude kudzu spread to adjacent plots. Treatments were made via two overlapping passes with an All terrain vehicle-mounted boomless nozzle in a total application volume of 374 L ha^{-1}. Kudzu management programmes began in July 2009 and measurements of aboveground kudzu biomass were taken June 2010 by harvesting all green kudzu biomass in an arbitrarily selected 0.3 m^2 area, air drying the plant material and comparing the dry weight to the weight of the biomass from surfactant-only treated plots. Each 0.3 m^2 area was destructively sampled in the harvest, but the larger, undisturbed, area of the plot was available for further treatments and analysis the following year. The treatments were reapplied to the same plots that year and assessed in June 2011 (Table 1). Percent control from the treatments was analysed by Tukey's mean separation test in JMP 11 (2015).

The one- and two-year control of kudzu by metsulfuron (72% and 89%, respectively) and aminopyralid (AMP) (79% and 85%, respectively) observed here is consistent with

Table 1. Kudzu management programmes.

Treatment (commercial product name)	Application rate[a]	Time of application 2009	Time of application 2010
Metsulfuron (Escort)	280 g ha^{-1}	8/27/2009	7/30/2010
AMP[b] (Milestone)	0.51 L ha^{-1}	8/26/2009	7/30/2010
Imazapic (Plateau)	0.87 L ha^{-1}	8/26/2009	7/30/2010
AMCP[c] low	140 g ha^{-1}	8/27/2009	7/30/2010
AMCP[c] high	280 g ha^{-1}	8/27/2009	7/30/2010
MV[d] early	7.5×10^{12} spore ha^{-1}	8/11/2009	7/30/2010
MV late	7.5×10^{12} spore ha^{-1}	9/25/2009	9/27/2010
MV 2×	7.5×10^{12} spore ha^{-1}	7/24/2009	7/30/2010
	7.5×10^{12} spore ha^{-1}	8/27/2009	9/27/2010
Mow 1×	n.a.	8/11/2009	8/31/2010
Mow 2×	n.a.	7/21/2009, 8/27/2009	7/30/2010, 9/13/2010
Mow	n.a.	7/21/2009	7/30/2010
MV	7.5×10^{12} spore ha^{-1}	8/11/2009	8/31/2010
Mow	n.a.	8/27/2009	9/13/2010
AMP	0.51 L ha^{-1}	9/11/2009	9/27/2010
MV	7.5×10^{12} spore ha^{-1}	7/24/2009	7/30/2010
Mow	n.a.	8/11/2009	8/31/2010
MV	7.5×10^{12} spore ha^{-1}	8/27/2009	9/13/2010
AMP	0.51 L ha^{-1}	9/11/2009	9/27/2010
AMP	0.51 L ha^{-1}	7/24/2009	7/30/2010
Mow	n.a.	8/11/2009	8/31/2010
MV	7.5×10^{12} spore ha^{-1}	8/27/2009	9/13/2010
Mow	n.a.	9/11/2009	9/27/2010

Note: n.a. – not applicable.
[a]Application rate determined by the label directions and expressed as formulated commercial product per hectare. All products applied in a 374 L ha^{-1} application volume and included. Induce non-ionic surfactant at 0.25%.
[b]Aminopyrialid.
[c]AMCP (DPX-MAT28) 'low' and 'high' indicate a 2 and 4 oz $acre^{-1}$ application rate, respectively.
[d]*Myrothecium verrucaria* spores applied at 2×10^7 spores mL^{-1} and 374 L ha^{-1}.

our earlier observations from three sites in Mississippi (Weaver et al., 2015) (Figure 1). These plots, however, represented our first experience with aminocyclopyrachlor (AMCP, DPX-MAT28). This chemical has been reported to be highly efficacious on a diverse spectrum of weeds (Bell, Burke, & Prather, 2011; Minogue et al., 2011). While there was no statistically significant separation in the herbicides evaluated here, nearly 100% control was realised with AMCP at the higher rate (280 g ha^{-1}) after two years of treatment. Imazapic is not labelled for kudzu control, but was included here because it could selectively control Johnson grass (*Sorghum halepense* (L.) Pers) while releasing some desirable grass species. Previous experiments in kudzu control resulted in unwanted Johnson grass emergence (Weaver et al., 2015). Imazapic was only evaluated for one year, when it provided 56% kudzu suppression.

A series of bioherbicide, mechanical and integrated programmes were tested for kudzu management alongside the herbicides (Figure 2). Mowing is not always an option because of the slopes where kudzu is frequently found, but it was found to be surprisingly effective in the present study, with two years of a single annual mowing event providing about 95% kudzu control in the subsequent year. The MV treatments were, overall, not as effective as mowing. Similar experiments with MV supplemented with low, sub-lethal rates of glyphosate (0.25×, 0.28 kg ha^{-1}) (Boyette, Weaver, et al., 2008; Boyette, Hoagland, & Weaver, 2008) have indicated significant synergy between MV and glyphosate. Even rates of glyphosate that are not appreciably herbicidal are known to interfere with plant defenses to some pathogens (reviewed in Johal & Huber, 2009; Duke et al., 2012). Greater efficacy may also be achieved through improved surfactant selection (Weaver, Jin, Hoagland, & Boyette, 2009). The present study, however, clearly indicates the potential of MV to control naturally occurring kudzu for multiple years. The kudzu suppression in the second year from the 2× MV treatment and the early season application were statistically similar to the Milestone, Escort and two AMCP treatments. Although greater

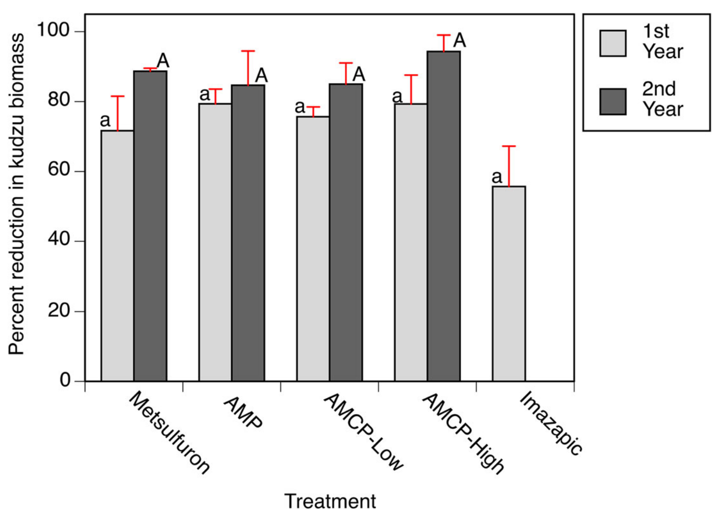

Figure 1. Kudzu biomass reduction (dry weight reduction expressed as % of untreated control) by herbicides. Error bars indicate one standard error of the mean. Treatments with the same letter are not separated by Tukey's test $\alpha = .05$. Lower case letters are for first-year treatments and upper case letters for second-year treatments. Treatments are described in text.

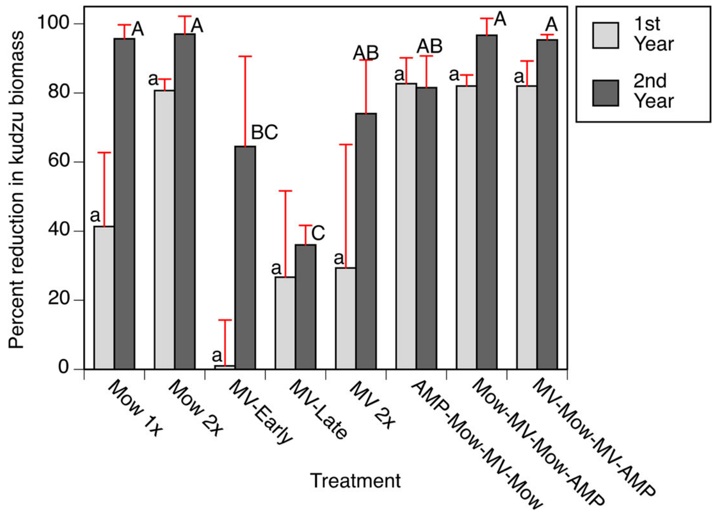

Figure 2. Kudzu biomass reduction (dry weight reduction expressed as % of untreated control) by biocontrol, mechanical control and integrated programmes. Error bars indicate one standard error of the mean. Treatments with the same letter are not separated by Tukey's test $\alpha = .05$. Lower case letters are for first-year treatments and upper case letters for second-year treatments. Treatments are described in text.

bioherbicidal efficacy has been documented elsewhere, the present study is unique in monitoring the multi-year control alongside the control provided by the newest, most effective herbicides.

It is questionable if MV treatments alone could practically result in kudzu eradication; so integrated programmes were also considered. All of the integrated programmes provided excellent kudzu control, with >80% control one year after initiation and two of the programmes approached 100% control after the second year. Because of the high efficacy of each of the components of the integrated programme, it is difficult to measure the added benefit of each additional component. Given the great growth potential of kudzu any control short of localised eradication would be a hollow victory, therefore control strategies are planned to include many years of treatment and monitoring. Over this time frame there may be opportunities for many control tactics to be employed at a given site. A sequential approach with multiple modes of action may facilitate a sustained, robust transition to more desirable vegetation and eradication of kudzu.

We have demonstrated here that a high level of kudzu suppression can be achieved rapidly. Kudzu suppression was successfully demonstrated through application of selective herbicides, a bioherbicide or combinations of treatments in an integrated control programme. This information will allow for long-term and sustainable control programmes to be developed from several treatment options.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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