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Control of Invasive Plant Mile-a-Minute (*Mikania micrantha*) with the Local Crop Sweet Potato (*Ipomoea batatas*) and Applications of the Herbicide Bentazon

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Abstract: Preventing the reinvasion and spread of invasive alien plants after chemical herbicide applications is a common challenge. A set of field experiments to examine the combined effect of competition with a local crop, sweet potato and the herbicide bentazon were conducted in Longchuan County of Yunnan Province, China. The results showed that the preferred plant ratio of sweet potato to mile-a-minute for effective control of mile-a-minute was at 2.5:1. The control rates were ranged from 77.35-90.59% when bentazon applied at 720-1080 g ai hm^{-2} and the selectivity index was 1.39. Compared to the application of bentazon alone at 1080 g ai hm^{-2}, inhibition rates for sweet potato and bentazon combined were higher, for a ratio of sweet potato to mile-a-minute of 2.5:1 with bentazon applied at 720 g ai hm^{-2}, beyond 30 days after the herbicide treatment. Compared with either sweet potato competition or bentazon application alone, the combined impact of sweet potato competition and bentazon application was significantly higher. The suppression rates of the two methods combined were higher than 90% for a ratio of sweet potato to mile-a-minute of 2.5:1 plus bentazon applied at 1080 g ai hm^{-2} from 30-120 days. All results suggested that sweet potato competition and bentazon combined could achieve more secure, sustainable and long term control of mile-a-minute.

Key words: Mile-a-minute (*Mikania micrantha*), sweet potato (*Ipomoea batatas*), bentazon, herbicide control, replacement control

INTRODUCTION

Mile-a-minute (*Mikania micrantha* H.B.K: Asteraceae), a perennial herb or semi-woody vine, is native to Central and South America (Zhang *et al*., 2004). It is one of the world's worst invasive alien species (Holm *et al*., 1991; Li *et al*., 2000; Lowe *et al*., 2000). The weed has been listed among the top 100 worst invasive species (Lowe *et al*., 2000; Zhang *et al*., 2004) and as one of the top 10 worst weeds in the world (Holm *et al*., 1991). Mile-a-minute is present in tropical Asia, parts of Papua New Guinea, Indian Ocean islands, Pacific Ocean islands and Florida in the USA (Zhang *et al*., 2004; Manrique *et al*., 2011). It has colonized a broad range of farming systems, forest lands, banks of streams, rivers, roadsides and railway tracks, pastures and open disturbed areas. In invaded habitats, due to rapid growth, vegetation smothering habit and production of allelochemicals, it has caused serious economic loss, biodiversity loss and negative environmental impacts (Zan *et al*., 2000; Zhang *et al*., 2004; Shen *et al*., 2013). According to Zhong *et al*. (2004), the economic impact of mile-a-minute on natural areas alone amounted to more than several hundreds of millions of dollars in China per year.

In order to control mile-a-minute, extensive study has been conducted on mechanical removal, chemical control, biological control and ecological control over the past two decades (Barreto and Evans, 1995; Kuo *et al*., 2002; Zhang *et al*., 2004; Moran *et al*., 2005; Yu *et al*., 2009; Shen *et al*., 2013). Currently, herbicides are most commonly used and the most effective control methods for mile-a-minute in many regions in most of countries, due to relatively high efficacy and better returns on

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application costs. However, because of large persistent soil seed banks, high reproductive capacity, ability to reshoot from stem fragments and roots of mile-a-minute (Abraham and Abraham, 2005), management of mile-a-minute by relying on herbicidal control is difficult. Thus, more comprehensive prevention and control measures such as community reconstruction and ecological approaches must be incorporated into management strategies.

Replacement control with high value species (e.g., local food, native species and/or cash crops) has recently emerged as a viable option for management of invasive alien plant species (Narwal, 2000; Sher *et al*., 2002; Jiang *et al*., 2008). As a potential alternative to traditional bio-control which generally employs insects or pathogens, replacement control relies on the growth advantage of one or more plants to suppress exotic plants, simultaneously reducing damage caused by the invasive species and improving local natural ecosystem health (Lugo, 1997; Jiang *et al*., 2008). Compared with mechanical or chemical control methods, replacement control is generally considered more secure, economical, ecological and sustainable (Jiang *et al*., 2008; Shen *et al*., 2012b; Shen *et al*., 2014). During ecological management of mile-a-minute, sweet potato [*Ipomea batatas* (L.) Lam.], an important locally grown cash crop, is observed to inhibit mile-a-minute growth in invaded farming communities in Longchuan County of Yunnan Province, China (Shen *et al*., 2012b) but the single planting is costly in terms of time and less efficient in short-term.

In order to solve the shortcomings arising from either a single herbicide application or the use of a replacement technique alone, a set of control experiments of mile-a-minute with sweet potato combined bentazon in Longchuan County was conducted. The study aimed to provide a scientific basis for setting up a long-term effective management utilizing ecological and chemical control techniques for mile-a-minute in the field.

MATERIALS AND METHODS

Study site: The study site was located in Longchuan County (24°08'-24°39' N, 97°39'-97°17' E), Dehong Prefecture, in the northwest end of Yunnan Province. This area is characterized by a typical tropical climate having a rainy season featuring heavy rainfall with 90% humidity alternating with a dry season. Rainfall averages 159.5 cm per year and the annual mean temperature is 18.9°C (Shen *et al*., 2012b). In recent years the range of mile-a-minute has been expanding rapidly within Longchuan County invading agricultural areas and forest margins.

Study species and herbicide: Mile-a-minute is one of the most serious invasive alien species in Dehong Prefecture and the total invaded area is estimated to be 8817.07 hm^2 (Mo, 2009). This perennial weed exhibits a climbing growth form in forests, orchards and shrublands but on roadsides, in wastelands and other areas without woody vegetation, it takes on a prostrate form. It has infested sugarcane, orange, banana, coffee, pineapple, bamboo, sweet potato, maize crops as well as artificial pasture and secondary forest in Longchuan County, Dehong Prefecture (Du *et al*., 2006; Shen *et al*., 2012a).

Sweet potato [*Ipomoea batatas* (L.) Lam: Convolvulaceae] is one of the main food and cash crops in tropical and subtropical regions of Yunnan Province. In Longchuan County, local villagers have grown it for over 100 years (Shen *et al*., 2012b). This herbaceous perennial vine usually exhibits a prostrate growth form in agricultural areas, so its niche is similar to that of mile-a-minute.

Bentazon (48%, EC) is a selective herbicide as it only damages plants unable to metabolize the chemical. It is considered safe for use on beans, corn, peanuts, peas, pepper, rice, sorghum and soybeans. Bentazon is usually applied aerially or through contact spraying on food crops to control the spread of weeds occurring amongst food crops.

Experiment design and data collection

Control of mile-a-minute by sweet potato: On 15 April 2012, above ground parts of mile-a-minute plants were collected from a population located in a nearby forest margin and sweet potato plants were collected from farmland near Zhangfeng Town of Longchuan County. Two-node segments (fresh weight 3.0-3.5 g, 7-9 cm pieces) of two species by choosing the newly growing plants from the old ones, similar in size, were selected from the middle of the stems to minimize the influence of phenotypic maternal effects. All materials were placed in Hoagland's solution (Hoagland and Arnon, 1950) and grown for 15 days. On 30 April 2012, the sprouts derived from cuttings of both species were transplanted in the field test plots. Six ratios of sweet potato and mile-a-minute plants were utilized (0:1, 1:1, 1.5:1, 2:1, 2.5:1 and 3:1) while maintaining a constant planting of 20 plants m^{-2}. All plots were arranged in a complete randomized design with 4 replicates utilizing 24 m^2 plots (4×6 m). All plants were distributed evenly within the plot. During the experiment, the two species exhibited prostrate growth.

After 30, 60, 90 and 120 days of planting, twenty plants of each species were selected at random and harvested in each plot. Mile-a-minute plants were carefully removed, separated, dried and weighed.

Bioassay and selectivity of bentazon for mile-a-minute and sweet potato: On 30 April 2012, the sprouts derived from cutting of both species were separately transplanted in 4 m^2 field plots while maintaining a constant planting of 20 plants m^{-2}. After 5 days of growth, the plants were sprayed with the bentazon (48%) at 0, 360, 540, 720, 1080 and 1440 g ai hm^{-2} for mile-a-minute and 0, 1080, 1440, 1800, 2160 and 2520 g ai hm^{-2} for sweet potato. The experimental design was completely randomized with 4 replicates per each concentration for both plant groups. Plants were sprayed with a 0.8 L pressure sprayer, while the control treatment plants were sprayed with water. After 25 days had elapsed after treatment, plant dry weights and symptoms of herbicide injury were recorded and then LD90 and selectivity index were calculated.

Control effects of sweet potato and bentazon combined on mile-a-minute: Based on former two field experimental results, the third experiment of sweet potato and bentazon combined to control mile-a-minute was conducted in 2013 growing season. On 25 April 2013, two-node segments (fresh weight 3.0-3.5 g, 7-9 cm pieces) of two species were selected from the middle of the stems to minimize the influence of phenotypic maternal effects. Care was taken to take the segments from young plants that were similar in size. All materials were placed in Hoagland's solution (Hoagland and Arnon, 1950) and grown for 15 days. On 10 May 2013, the sprouts derived from cutting of mile-a-minute and sweet potato plants were transplanted in the field test plots. Three ratios of sweet potato and mile-a-minute plants were utilized (0:1, 2:1 and 2.5:1) while maintaining a constant planting of 20 plants m^{-2}. All plants were distributed evenly within the plot. After 5 days of growing, the plants were sprayed with the bentazon (48%), each at the concentrations of (0, 720 and 1080 g ai hm^{-2}). The experimental design was a two-factor factorial arranged as a randomized complete block with 4 replications utilizing 24 m^2 plots (4×6 m). Plants were sprayed with spraying liquid volume 450 kg hm^{-2}, application equipment for the Singapore Linon HD400 knapsack sprayer, while the control treatment plants were sprayed with water. Plant dry weights and symptoms of herbicide injury were recorded after 30, 60, 90 and 120 days.

Data analyses: Efficacy of mile-a-minute control and toxicity rate on sweet potato were calculated and assessed. Utilizing the regression equation for herbicide dosage (X) and strain prevention efficiency (%), LD90 and selectivity index were measured. LD90 is the herbicide dosage when prevention efficiency of mile-a-minute is over 90% and selectivity index is equal to sweet potato LD10/mile-a-minute LD90. A higher selectivity index means stronger selectivity and higher safety to no-target plants. The suppression equation was:

$$\text{Prevention efficiency (\%)} = \frac{[\text{CK (density or dry weight)} \\ \text{-treatment (density or dry weight)}]}{\text{CK (density or dry weight)}} \times 100$$

Data was analysed by analysis of variance (one-way ANOVA). If significant differences were detected with the ANOVA, Duncan's multiple range tests were used to detect differences among treatments at a 5% level of significance.

RESULTS

Sweet potato on mile-a-minute: In mixed culture, the replacement control rates of sweet potato on mile-a-minute were greatly increased with increasing proportions of sweet potato and growing period (Table 1). After 30 days planting, the inhibition rates were 21.13-49.62% and significantly increased with declining proportions of mile-a-minute. The suppressed rates were significantly increased with declining proportions of mile-a-minute for ratios of sweet potato to mile-a-minute of 1:1, 1.5:1, 2:1 and 2.5:1 after 60, 90 and 120 days planting. However, for ratios of sweet potato to mile-a-minute of 2.5:1 and 3:1, the inhibited rates were gradually increased as proportions of sweet potato increased in mixed culture but there were not significant from 60-120 days growth. The preferred plant ratio of sweet potato to mile-a-minute for effective control of mile-a-minute was 2.5:1.

Table 1: Replacement control effect of sweet potato on mile-a-minute 30-120 days after planting

	Suppressed rate (%)			
Ratios (Sweet potato: Mile-a-minute)	30	60	90	120
1:1	21.13±0.04^e	32.25±0.14^d	44.22±0.19^d	51.91±0.42^d
1.5:1	25.01±0.08^d	37.14±0.15^c	48.17±0.29^c	55.36±0.48^c
2:1	32.53±0.13^c	41.42±0.18^b	53.54±0.43^b	59.42±0.52^b
2.5:1	40.24±0.20^b	48.94±0.37^a	61.15±0.61^a	65.75±0.67^a
3:1	49.62±0.28^a	50.13±0.41^a	63.62±0.65^a	67.23±0.69^a

Data is expressed as Means±SD. The different letters within same column signify significant differences at $p<0.05$

Table 2: Toxicity and selectivity of bentazon to mile-a-minute and sweet potato

	Mile-a-minute		Sweet potato	
Herbicide dosage (g ai hm^{-2})	Biomass (g/plant)	Suppressed rate (%)	Biomass (g/plant)	Suppressed rate (%)
0	2.87 ± 0.08^{a}	-	8.66 ± 0.35^{a}	-
360	1.56 ± 0.03^{b}	45.64 ± 0.21^{e}	-	-
540	0.83 ± 0.01^{c}	71.08 ± 0.28^{d}	-	-
720	0.65 ± 0.01^{d}	77.35 ± 0.27^{c}	-	-
1080	0.27 ± 0.01^{e}	90.59 ± 0.29^{b}	8.55 ± 0.12^{a}	1.27 ± 0.01^{e}
1440	0.12 ± 0.01^{f}	95.82 ± 0.30^{a}	8.08 ± 0.09^{b}	6.70 ± 0.01^{d}
1800	-	-	7.65 ± 0.05^{c}	11.66 ± 0.01^{c}
2160	-	-	6.55 ± 0.06^{d}	24.36 ± 0.08^{b}
2520	-	-	5.26 ± 0.04^{e}	39.26 ± 0.11^{a}

Data is expressed as Means±SD. The different letters within same column signify significant differences at $p<0.05$

Table 3: Mile-a-minute control by sweet potato and bentazon combined

			Mile-a-minute control (days)							
			30		60		90		120	
Treatments	Ratios (Sweet potato: Mile-a-minute)	Herbicide dosage (g ai hm^{-2})	Biomass (g/plant)	Suppressed rate (%)	Biomass (g/plant)	Suppressed rate (%)	Biomass (g/plant)	Suppressed rate (%)	Biomass (g/plant)	Suppressed rate (%)
1	2:1	1080	0.19 ± 0.01^{h}	93.19 ± 0.57^{ab}	1.28 ± 0.01^{g}	91.48 ± 0.61^{a}	4.61 ± 0.13^{f}	84.71 ± 0.44^{b}	9.86 ± 0.30^{f}	79.18 ± 0.63^{b}
2	2:1	720	0.49 ± 0.01^{e}	82.44 ± 0.65^{d}	2.98 ± 0.05^{e}	80.16 ± 0.27^{c}	7.35 ± 0.26^{d}	75.62 ± 0.52^{c}	14.03 ± 0.37^{d}	70.38 ± 0.57^{d}
3	2:1	0	1.91 ± 0.04^{b}	31.54 ± 0.13^{g}	8.59 ± 0.11^{b}	42.81 ± 0.33^{f}	13.64 ± 0.62^{b}	54.76 ± 0.16^{e}	19.22 ± 0.58^{b}	59.42 ± 0.62^{f}
4	2.5:1	1080	0.13 ± 0.01^{i}	95.34 ± 0.79^{a}	0.94 ± 0.01^{h}	93.74 ± 0.15^{a}	2.24 ± 0.05^{g}	92.57 ± 0.38^{a}	4.32 ± 0.10^{g}	90.88 ± 0.25^{a}
5	2.5:1	720	0.35 ± 0.01^{f}	87.46 ± 0.29^{c}	2.18 ± 0.04^{f}	85.49 ± 0.29^{b}	4.92 ± 0.08^{ef}	83.68 ± 0.31^{b}	9.24 ± 0.37^{f}	80.49 ± 0.71^{b}
6	2.5:1	0	1.69 ± 0.07^{c}	39.43 ± 0.21^{f}	7.56 ± 0.05^{c}	49.67 ± 0.12^{e}	11.53 ± 0.75^{c}	61.76 ± 0.19^{d}	16.13 ± 0.65^{c}	65.94 ± 0.64^{e}
7	0:1	1080	0.27 ± 0.01^{g}	90.32 ± 0.29^{b}	2.24 ± 0.02^{f}	85.09 ± 0.14^{b}	5.46 ± 0.07^{e}	81.89 ± 0.42^{b}	11.35 ± 0.49^{e}	76.03 ± 0.51^{c}
8	0:1	720	0.64 ± 0.01^{d}	77.06 ± 0.51^{e}	4.36 ± 0.06^{d}	70.97 ± 0.41^{d}	11.08 ± 0.08^{c}	63.25 ± 0.29^{d}	19.07 ± 0.93^{b}	59.73 ± 0.49^{f}
9	0:1	0(CK)	2.79 ± 0.11^{a}	-	15.02 ± 0.51^{a}	-	30.15 ± 1.06^{a}	-	47.36 ± 1.82^{a}	-

Data is expressed as Means±SD. The different letters within same column signify significant differences at $p<0.05$

Bioactivity and selectivity for mile-a-minute and sweet potato: From the herbicide dosage (X) and strain prevention efficiency (%) of mile-a-minute, the toxicity regression equation for mile-a-minute was derived as:

$$Y = 0.95x+19.712,\ R^2 = 0.832$$

and the LD90 was 1109.85 g ai hm^{-2} (Table 2). According to the regression equation with herbicide dosage (X) and strain prevention efficiency (%) of sweet potato, the toxicity regression equation for sweet potato was:

$$Y = 0.3902\times\text{-}30.17,\ R^2 = 0.9417$$

and LD10 was 1544.25 g ai hm^{-2}:

$$\text{Selectivity index} = \frac{\text{Sweet potato LD10}}{\text{Mile-a-minute LD90}} = 1.39$$

It indicates that bentazon has excellent selectivity for sweet potato under effective control of mile-a-minute. Finally, the control rates ranged from 77.35-90.59% when bentazon was applied at 720-1080 g ai hm^{-2} and which were safe rates for sweet potato.

Combined effects of sweet potato and bentazon on mile-a-minute: Treatments 3 and 6 tested control of mile-a-minute via sweet potato competition alone. The suppression rates utilizing sweet potato competition against mile-a-minute were significantly increased with increasing growing period (Table 3). Treatments 7-8 tested control of mile-a-minute via bentazon control alone. Inhibition rates of mile-a-minute via bentazon alone greatly declined with increasing growing period. Except for the ratio of sweet potato to mile-a-minute of 2.5:1 after 120 days, the inhibited rates of single replacement control were much lower than a single bentazon application between 30 and 90 days.

Treatments 1, 2, 4 and 5 tested the combined effects of sweet potato competition and bentazon on mile-a-minute. Mile-a-minute inhibition rates were 82.44-95.34% after 30 days, 80.16-93.74% after 60 days, 75.62-92.57% after 90 days and 70.38-90.88% after 120 days, respectively. Compared to single treatments involving sweet potato or bentazon, suppression of mile-a-minute by sweet potato and bentazon combined were obviously higher. The suppression rates on mile-a-minute for the two methods combined were higher than 90% for a ratio of sweet potato to mile-a-minute of 2.5:1 with bentazon applied at 1080 g ai hm^{-2} from 30-120 days. Compared to the application of bentazon alone at 1080 g ai hm^{-2}, inhibition rates for sweet potato and bentazon combined were higher, for a ratio of sweet potato to mile-a-minute of 2.5:1 with bentazon applied at 720 g ai hm^{-2}, beyond 30 days after the herbicide treatment.

DISCUSSION

In this study, it was found that bentazon is an effective herbicide and sweet potato is a potentially effective replacement crop for mile-a-minute control. When bentazon was applied at 720-1080 g ai hm^{-2} effective control of mile-a-minute was achieved at a level that did not damage sweet potato. The inhibition rates of sweet potato alone on mile-a-minute were low in the short term and significantly increased with increasing growth. Suppression by sweet potato competition and bentazon combined was clearly higher than by sweet potato or bentazon in isolation. Moreover, a ratio of sweet potato to mile-a-minute of 2.5:1 with bentazon applied at 1080 g ai hm^{-2} was the best treatment for mile-a-minute control because mile-a-minute was still over than 90% inhibited, 120 days after herbicide treatment. Compared to applying bentazon alone at 1080 g ai hm^{-2}, beyond 30 days after the application, inhibition rates of mile-a-minute were higher via sweet potato and bentazon combined for a ratio of sweet potato to mile-a-minute of 2.5:1 for bentazon applied at 720 g ai hm^{-2}. All of these results showed that lower bentazon dosage and combined sweet potato also could achieve higher effective and sustainable control on mile-a-minute.

For effective management of mile-a-minute, herbicides are still preferred over other control methods. Chemical herbicides such as 2, 4-D, paraquat, sulfometuron-methyl, hexazinone, glyphosate, picloram, oxadiazon, napropamide, atrazine and starane, aminocyclopyrachlor, aminopyralid, fluroxypyr, bromoxynil octanoate, dicamba, fluroxypyr meptyl, glufosinate ammonium, glyphosate isopropylammonium and triclopyr are effective against mile-a-minute (Wang *et al*., 2003; Shen *et al*., 2013; Guo *et al*., 2014; Sellers *et al*., 2014). A rate of 0.4% bentazon was the most effective herbicide against 25, 45 and 60 day-old mile-a-minute seedlings and inhibited seed germination (Hu and Bi, 1994). However, many herbicides are usually low security for non-targets and only control mile-a-minute for a relatively short period. Therefore, the specific herbicides utilized must be adjusted to specific communities and habitats.

The screening of native species or associated high value plants with strong competitive ability (e.g., local food and/or cash crops), is an important initial step for ecological management of invasive alien species. Competition between various locally available plants and mile-a-minute has recently been studied in China. A study found that *Cuscuta campestris* could reduce the competitive ability of mile-a-minute and benefit species richness and recovery of native communities (Yu *et al*., 2009). The growth, biomass, reproduction and nutrients (i.e., N, P and K content) of mile-a-minute were inhibited following parasitism by *C. campestris* (Yu *et al*., 2009; Shen *et al*., 2011). *Cuscuta campestris* significantly reduces photosynthesis in mile-a-minute by blocking sunlight as well as capturing resources from the host plants (Shen *et al*., 2011). However, land managers must be cognizant that *C. campestris* is parasitic and may affect other plants. Xu *et al*. (2011) reported that *Lolium perenne*, *Artemisia annua* and *Festuca elata* had stronger competitive ability than mile-a-minute seedling but competitive ability of *Alsike clover* and *Medicago sativa* was weaker.

Shen *et al*. (2012b) found that in monoculture, the total biomass, node number and biomass of adventitious root, leaf stalk length and leaf area of sweet potato were all higher than those of mile-a-minute and in mixed culture the plant height, branch, leaf, stem node, adventitious root and biomass of mile-a-minute were suppressed significantly. Because of similar niche between sweet potato and mile-a-minute, higher node number and biomass of adventitious root and larger leaf stalk length and leaf area of sweet potato successfully competes for water, nutrients, light and space and replace mile-a-minute. Another study found that sweet potato could significantly reduce population density and importance values of invasive alien species *Ageratum conyzoides*, *Bidens pilosa*, *Eleusine indica* and *Galinsoga parviflora* and native species, *Digitaria sanguinalis* and *Portulaca oleracea* (Shen *et al*., 2014), indicating sweet potato also could be widely used in farming systems.

CONCLUSION

Compared to use of sweet potato competition or bentazon application in isolation, the combination of two techniques should yield social, ecological and economic benefits for mile-a-minute management. Sweet potato is one of the main food and cash crops in tropical and subtropical regions of the world and is widely cultivated by local villagers in regions of Yunnan Province, China. The above ground parts of the plant are used for livestock fodder and its roots are provided for human consumption and market. Moreover, sweet potato planted in combination with bentazon applications could achieve more secure and long term control of mile-a-minute. Reducing bentazon dosage also could decrease in labour costs and negative environmental impacts. Thus, for better management of invasive plants such as mile-a-minute, a combination of sweet potato cultivation and bentazon application provide a very accessible approach that could be readily adopted by farmers. Moreover, these methods used in this study could be adapted to and applied to other crops/weeds in the future.

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