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# Evaluation of Herbicides and Application Rates for Mugwort (*Artemisia vulgaris* L.) Management in Cool Season Forage Grasses

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**ABSTRACT**
A 3-yr field experiment evaluated different herbicides and application rates for mugwort management in a permanent grassland. The main plot had three herbicides, aminopyralid, clopyralid, and glyphosate; and the subplot had three application rates, aminopyralid (61, 122, and 244 g ae ha$^{-1}$), clopyralid (140, 280, and 560 g ae ha$^{-1}$), and glyphosate (552, 1,104, and 2,208 g ae ha$^{-1}$). Results revealed that only glyphosate caused significant injury to forage grasses, which varied from 65 to 100% depending upon application rate. Neither aminopyralid nor clopyralid caused noticeable injury to forage grasses. By 9 months after initial herbicide treatment (MAIT), mugwort was controlled 60 to 98% with aminopyralid at ≥61 g ae ha$^{-1}$ or glyphosate at ≥552 g ae ha$^{-1}$. By 21 MAIT, aminopyralid at ≥122 g ae ha$^{-1}$ or glyphosate at ≥1,104 g ae ha$^{-1}$ resulted in at least 95% reduction in mugwort rhizome biomass and provided 98% or higher visual control. By 33 MAIT, complete control of mugwort was confirmed in plots treated with aminopyralid at ≥122 g ae ha$^{-1}$ or glyphosate at ≥1,104 g ae ha−1. Clopyralid was not effective; mugwort control was < 40% even after three annual applications at 560 g ae ha$^{-1}$.

**INTRODUCTION**
Mugwort (*Artemisia vulgaris* L.), was introduced from Europe into North America more than 400 years ago as a medicinal herb. Historically, mugwort invasion was confined to roadsides, floodplains and riparian areas, rights-of-way, and turf and landscape settings (Ahrens 1976; Bing 1983; Bingham 1965; Henderson and Weller 1985; Holm et al. 1997). Recently, it has begun encroaching into annual row crops such as corn, cotton, and soybean and into pastures and hayfields (Barney and DiTommaso 2003; Bradley and Hagood 2002a, 2002b). The rapid spread of mugwort is attributed to its extensive underground rhizome system and inconsistent control with chemical and cultural control tactics. Mugwort can spread via both rhizomes and seed. However, rhizomes are believed to be the primary method in the northeastern United States. Production of viable seeds has also been reported (JS Aulakh, unpublished data; Barney and DiTommaso 2003). Mugwort is also one of the 10 most troublesome weeds in the U.S. nursery industry, where it strongly interferes with the growth of ornamental plants (Ahrens 1976; Henderson and Weller 1985; Holm et al. 1997; Pridham and Bing 1963). It is a serious threat to the diversity of native flora, especially early successional species (Barney and DiTommaso 2003; Holm et al. 1997). Allelochemicals produced by mugwort are known to adversely impact pasture species. LeFevre and Chappell (1962) observed inhibition of alfalfa seed germination and seedling growth with fresh and dried mugwort extracts. Decaying foliage and rhizomes of mugwort inhibited seedling growth of red clover (Inderjit and Foy 1999; Inderjit et al. 2001).

Many approaches have been used for mugwort management. These include, herbicides and combination of multiple approaches. Bingham (1965) observed a 65% reduction in mugwort rhizome biomass in mowed plots compared with non-mowed plots. Other researchers observed no mugwort control following two sequential mowings at a 5-wk interval (Bradley and Hagood 2002b). Sequential mowing at 10-, 15-, and 30-day interval from May through September over two consecutive years reduced mugwort rhizome less than 30% (JS Aulakh, unpublished data). Physical control methods, such as tilling, are not effective and inadvertently contribute to the spread of the plant (Klingeman et al. 2004; Rogerson 1964).

Herbicides such as aminopyralid, clopyralid, glyphosate, and picloram have provided variable control of mugwort. Once the treatments ceased, regrowth of mugwort occurred a year after treatment. This was in part attributable to mugwort's persistent rhizome system and in part to the absence of competitive ground cover following chemical removal of mugwort. Previous research efforts were mainly focused at achieving satisfactory control of aboveground mugwort biomass. These studies did not aim for complete elimination of rhizomes for long term management of mugwort. Therefore, a multi-year field experiment was conducted to evaluate the effectiveness of sequential annual treatments of different herbicides and their application rates for mugwort control and rhizome elimination in cool season forage grasses.

## MATERIALS AND METHODS

A 3-yr field experiment was conducted at the Lockwood Research Farm of the Connecticut Agricultural Experiment Station in Hamden, CT from 2015 through 2018. The research site was a permanent grassland composed of Kentucky bluegrass, orchard grass, and Timothy-grass. The soil at the experiment site was a Yalesville well-drained, gravelly, sandy loam with 64% sand, 29% silt, 7% clay, 3.7% organic matter, and a pH of 5.6. Before the study, the site was mowed once in June 2015. The experiment was established in a split-plot design with three replications. The main plot (9 by 9 m) included three herbicides (aminopyralid, clopyralid, and glyphosate), and the subplot (3 by 9 m) was three application rates. Aminopyralid (Milestone™) rates were 61, 122, and 244 g ae $ha^{-1}$, clopyralid (Stinger®) rates were 140, 280, and 560 g ae $ha^{-1}$, and glyphosate (Roundup PowerMax®) rates were 552, 1,104, and 2,208 g ae $ha^{-1}$ . A nontreated control plot (no herbicide) also was established for comparison. Each year, the entire experiment site was mowed once in late July or early August. Herbicide treatments were applied on October 23, 14, and 6 in 2015, 2016, and 2017, respectively. Herbicide solutions were prepared in deionized water and applied with a compressed CO2 sprayer fitted with four XR TeeJet® 8002 nozzles delivering 187 L $ha^{-1}$ at 276 kPa. A nonionic surfactant (Activator 90) (0.5% v/v) was used with the aminopyralid treatments only. Data were collected periodically over the 3 years for forage grass injury, mugwort visual control, and rhizome dry biomass. Mugwort control and forage grass injury were assessed visually using a scale ranging from 0% (no control or injury) to 100% (complete control or death). Visual mugwort control and forage injury estimates at 9, 21, and 33 months after initial herbicide treatment (MAIT) were based on chlorosis, necrosis, and stunting of the treated plants compared with the plants in the nontreated control plots. Mugwort rhizome dry biomass were sampled at 9, 21, and 33 MAIT within two randomly placed 50 by 50 cm.

## RESULTS AND DISCUSSION

**Grass Injury:** Neither aminopyralid nor clopyralid caused noticeable injury to forage grasses. Both aminopyralid and clopyralid are labeled for use on established desirable grasses. Aminopyralid can be applied in the spring before seeding grasses in the following fall (Halstvedt et al. 2011; Lym et al. 2017). Similarly, newly seeded pubescent wheatgrass was not injured with clopyralid at 0.07 kg ae $ha^{-1}$ (Enloe et al. 2005). All rates of glyphosate tested in this study were highly injurious to established cool-season grasses. With 552 g ae $ha^{-1}$ of glyphosate, injury manifested mainly as chlorosis and stunting. Averaged across nitrogen rates and MAIT, grass injury with 552 g ae $ha^{-1}$ of glyphosate was around 65% compared with the nontreated control. Glyphosate at 1,104 g ae $ha^{-1}$ or higher resulted in complete elimination of cool-season grasses. Early symptoms included chlorosis, which was soon followed by complete tissue necrosis over a period of 4 to 5 weeks. Previously, Bingham et al. (1980) also observed 63 to 85% reduction in shoot dry weight in 4-month old Kentucky bluegrass, orchardgrass, and perennial ryegrass with glyphosate at 280 g ae $ha^{-1}$ or higher in a greenhouse study.

**Mugwort Visual Control**: Mugwort was effectively controlled with all tested rates of aminopyralid and glyphosate at 1,104 g ae $ha^{-1}$ or higher. With aminopyralid, mugwort control increased from 75 to 95% with 61 g ae $ha^{-1}$, 90 to 99% with 122 g ae $ha^{-1}$, and 98 to 99% with 244 g ae $ha^{-1}$, from 9 to 33 MAIT, respectively (Figure 1A). Previously, Koepke-Hill et al. (2011) also found aminopyralid to be highly effective on mugwort, with 52, 91, and 97% control a year following treatment with aminopyralid at 70, 140, and 280 g ae $ha^{-1}$, respectively. Clopyralid had little effect, and there was no improvement in mugwort control over time (Figure 1B). Early symptoms of clopyralid injury included: chlorosis, curling of leaves and shoots, and necrosis. However, mugwort recovered after each treatment, and only stunting injury was present at the time of visual control estimates.

Averaged across MAIT, visual control was less than 40% even with the highest clopyralid rate of 560 g ae $ha^{-1}$. Regarding glyphosate, mugwort was controlled 60% at 552 g ae $ha^{-1}$ and 90% or higher with at least 1,104 g ae ha$^{-1}$ by 9 MAIT (Figure 1C). Regardless of glyphosate rate, there was no significant improvement in control by 21 MAT and afterward. By 33 MAIT, mugwort was controlled >99% with at least 1,104 g ae ha$^{-1}$. In this study, glyphosate at 1,104 g ae ha$^{-1}$ gave 90% or higher control by 9 MAIT, which is more than the 74% control reported 1 year after treatment with glyphosate at 2,200 g ae ha$^{-1}$ in Virginia (Bradley and Hagood 2002a).

**Mugwort Rhizome Elimination**: Mugwort frequently evades control with herbicides because of its persistent rhizome system. Therefore, complete elimination of rhizomes is critical for achieving long-term control. Mugwort rhizome biomass in the nontreated plots was 448, 460, and 528 g m$^{-2}$ at 9, 21, and 33 MAIT, respectively. Overall, the reduction in the rhizome biomass corresponded with the percent visual control. By 9 MAIT, aminopyralid reduced rhizome biomass 73 to 91% depending upon application rate (Figure 2A), whereas the corresponding visual control estimates were slightly higher (Figure 1A). By 21 MAIT, rhizomes were completely eliminated within the sampled quadrats with at least 122 g ae ha$^{-1}$ of aminopyralid. By 33 MAIT, all rates of aminopyralid were similar; however, rhizomes were still not completely eliminated with aminopyralid at 61 g ae ha$^{-1}$. No previous research has ever quantified reduction in mugwort rhizome biomass following chemical control. With clopyralid, reductions in rhizome biomass closely followed the visual control estimates. Rhizome biomass was reduced only 14, 29, and 38% with 140, 280, and 560 g ae ha$^{-1}$ respectively, when compared with the nontreated control (Figure 2B). Clopyralid at 140 g ae ha$^{-1}$ was not different from the nontreated control. An approximate 35% reduction in rhizome biomass occurred following initial treatment of clopyralid at ≥280 g ae ae ha$^{-1}$. With glyphosate, reduction in rhizome biomass ranged from 52 to 91% by 9 MAIT, 58 to 100% by 21 MAIT, and 60 to 100% by 33 MAIT, depending upon glyphosate rate (Figure 2C). By 21 MAIT and afterward, glyphosate at 1,104 g ae ha$^{-1}$ or higher resulted in complete elimination of rhizome biomass. Glyphosate at or greater than 1,104 g ae ha$^{-1}$ and aminopyralid at or greater than 122 g ae ha$^{-1}$ were similar in terms of elimination in rhizome biomass On the contrary, glyphosate at 552 g ae ha$^{-1}$ was not as effective as 61 g ae ha$^{-1}$ of aminopyralid at any timing

## SUMMARY

The rhizome biomass and visual control results have shown that mugwort was completely controlled with aminopyralid at 244 g ae ha$^{-1}$ by 21 MAIT. Complete control of mugwort was also confirmed with three annual applications of aminopyralid at 122 g ae ha$^{-1}$ or glyphosate at 1,104 g ae ha$^{-1}$ or higher by 33 MAIT. Similarly, two annual applications of glyphosate at 1,104 g ae ha$^{-1}$ or higher resulted in at least 98% visual control and reduction in rhizome biomass by 21 MAIT.

This study has shown that mugwort can be managed in cool season forage grasses with sequential low rates of aminopyralid. Aminopyralid is currently not registered for use on cool-season grass pastures or hayfields in many states in the Northeast, likely because of its long soil persistence (half-life, 31 to 533 d) and risk of injury to sensitive crops via contaminated manure. However, many aminopyralid containing herbicides may be used on grazed areas in and around rangelands, conservation reserve program, natural areas, and noncrop areas. As regards glyphosate, being a nonselective herbicide, glyphosate may perhaps be used for spot treatment of isolated mugwort patches or where reseeding is the only economic alternative, especially where dense mugwort infestations have significantly displaced the desirable grasses. Although clopyralid is labeled for use on grass pastures, hayfields, and rangelands, it did not appear to provide satisfactory control of mugwort at the rates tested in this study.

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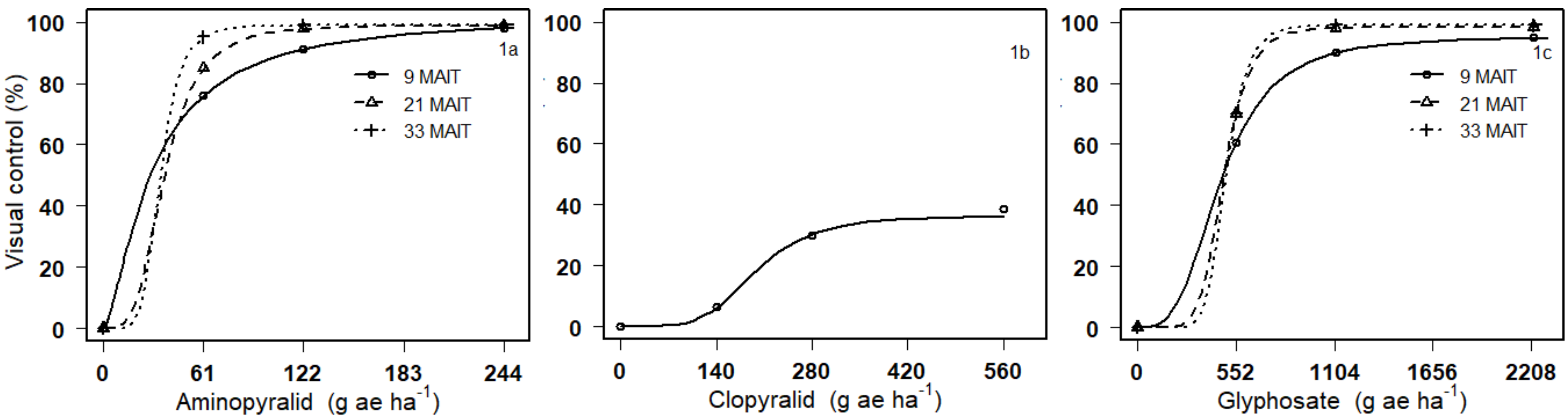


Figure 1a-c. Mugwort percent visual control under different rates of aminopyralid (1a); clopyralid (1b); and glyphosate (1c) at 9, 21, and 33 MAIT. Because the clopyralid rate by MAIT interaction was not significant, single response curve is given for clopyralid.

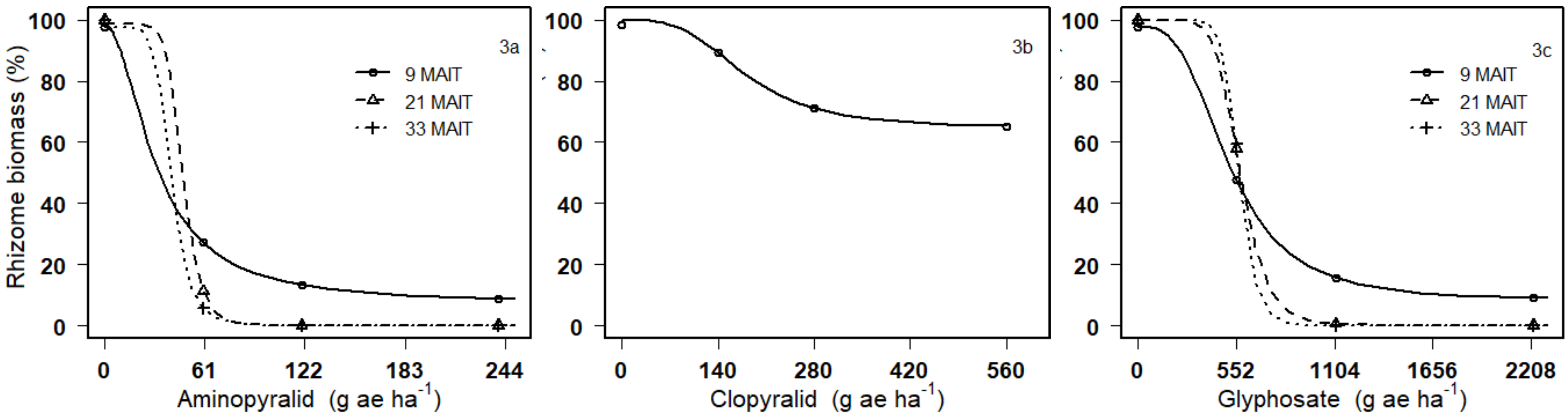


Figure 2a-c. Mugwort rhizome biomass (%) reduction compared to the non-treated control with different rates of aminopyralid (3a); clopyralid (3b); and glyphosate (3c) at 9, 21, and 33 MAIT. Because the clopyralid rate by MAIT interaction was not significant, single response curve is given for clopyralid